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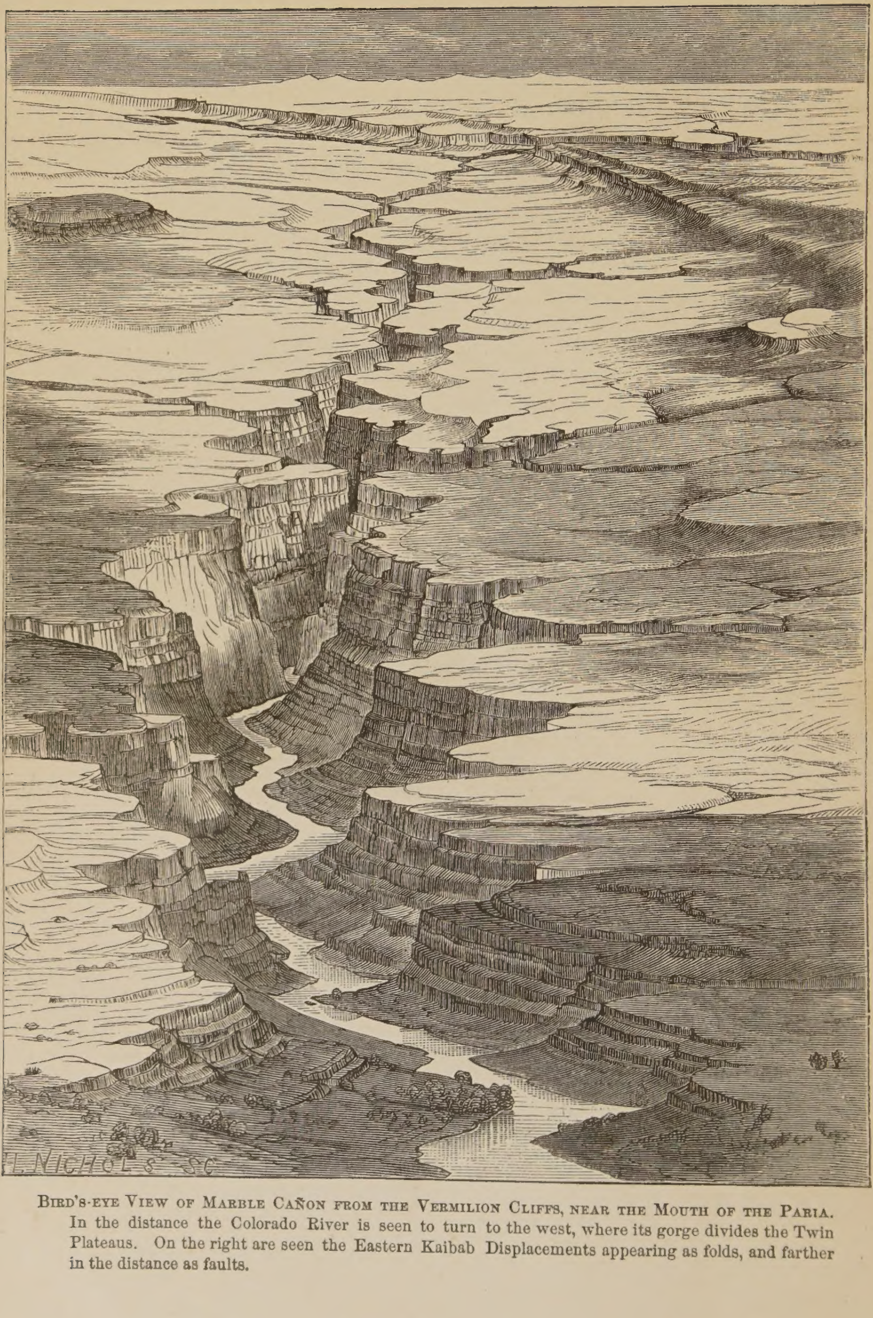

Bird's-eye View of Marble Cañon from the Vermilion Cliffs, near the Mouth of the Paria. In the distance the Colorado River is seen to turn to the west, where its gorge divides the Twin Plateaus. On the right are seen the Eastern Kaibab Displacements appearing as folds, and farther in the distance as faults.

ELEMENTS

OF

GEOLOGY:

A TEXT-BOOK

FOR

COLLEGES AND FOR THE GENERAL READER.

BY

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REVISED AND ENLARGED EDITION.

[redacted]

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PREFACE TO REVISED EDITION.

In preparing this revision of my "Elements of Geology," my endeavor has been, while retaining the general plan, to make such changes and additions as were rendered necessary by the rapid advance of geological science, especially in this country.

In Part I. the most important changes are the addition of Croll's and Thomson's theories of glacier motion, and some modifications of statement concerning the origin of the Peninsula of Florida.

In Part II. several sections, especially those on the "Form of the Earth," on "Mineral Veins," and on "Mountain Chains," have received considerable modifications. The chapter on "Igneous Rocks" has been entirely rewritten and greatly enlarged ; and it is hoped that this difficult subject is now presented in a form which more nearly represents the present condition of lithology. In preparing this chapter, I have received important aid from Mr. A. W. Jackson, the mineralogist of the University of California.

In Part III. the changes are numerous. The most important are as follows : I have embodied a brief account of the recent discoveries in our Western strata, by Marsh and Cope, of Permian and Jurassic reptiles, and by Marsh of Jurassic mammals and Cretaceous birds. I have added the most important results of the investigations of King in regard to the tertiary and quaternary lakes of the Rocky Mountain region ; and of Chamberlin, Upham, and others, in regard to the ice-sheet moraine. I have also given somewhat fully Croll's theory of the climate of the glacial epoch, and Wallace's modification of the same. These changes have involved the addition of many new figures.

I desire to acknowledge my indebtedness to Prof. Marsh for many important suggestions in regard to the history of mesozoic reptiles and birds, to Prof. Newberry for corrections of some inaccuracies in the previous edition, and to Mr. W. Le Conte Stevens for personal assistance in conducting the work through the press.

Berkeley, Cal., *July*, 1882.

PREFACE.

In preparing the following work I have not attempted to make an exhaustive *manual* to be thumbed by the special student; for, even if I felt able to write such a work, Prof. Dana's is already in the field, and is all that can be desired in this respect. I have endeavored only to present clearly to the thoroughly cultured and intelligent student and reader whatever is best and most interesting in Geological Science. I have attempted to realize what I conceive to be comprised in the word *elements*, as contradistinguished from *manual.* I have attempted to give a really scientific presentation of all the departments of the wide field of geology, at the same time avoiding too great multiplication of detail. I have desired to make a work which shall be both interesting and profitable to the intelligent general reader, and at the same time a suitable text-book for the higher classes of our colleges. In the selection of material and mode of presentation I have been guided by long experience, as to what it is possible to make interesting to a class of young men, somewhat advanced in general culture and eager for knowledge, but not expecting to become special geologists. In a word, I have tried to give such knowledge as every thoroughly cultured man ought to have, and at the same time is a suitable foundation for the further prosecution of the subject to those who so desire. The work is the substance of a course of lectures to a senior class, organized, compacted, and disencumbered of too much detail, by re-presentation for many successive years, and now for the first time reduced to writing.

Most text-books now in use in this country are, in my opinion, either too elementary on the one hand, or else adapted as manuals for the specialists on the other. I wish to fill this gap—to supply a want

felt by many intelligent students and general readers, who desire a really scientific general knowledge of geology. Lyell's "Elements" comes nearest to supplying this want; but there are two objections to this admirable work: 1. The principles (dynamical geology) are separated from the elements (structural and historical geology), and treated in a different work; 2. Its treatment of *American* geology is of course meagre.

I have treated several subjects in dynamical and structural geology —e. g., rivers, glaciers, volcanoes, geysers, earthquakes, coral-reefs, slaty cleavage, metamorphism, mineral veins, mountain-chains, etc. —more fully than is common. I feel hopeful that many geologists and physicists will thank me for so doing. I am confident that I give somewhat fairly the present condition of science on these subjects.

In the historical part I have found much more difficulty in being scientific without being tiresome, and in being interesting without being superficial and wordy. I have attempted to accomplish this difficult task by making *evolution* the central idea, about which many of the facts are grouped. I have tried to keep this idea in view, as a thread running through the whole history, often very slender—sometimes, indeed, invisible—but reappearing from time to time to give consistency and meaning to the history.

If this work have any advantage over others already before the public, it is chiefly in the two points mentioned above, viz., in a fuller presentation of some subjects in dynamical and structural geology, and in the attempt to keep evolution in view, and to make it the central idea of the history. Another advantage, I believe, is, that it does not seek to compete with the best works now before the public, but occupies a distinct field and supplies a distinct want.

I have confined myself mostly, though not entirely, to American geology, especially in giving the distribution of the rocks and the physical geography of the different periods. In only one case have I made American geology subordinate, viz., in the Jura-Trias period, and that only because of the meagreness of the record of this period in this country.

In a science so comprehensive and many-sided as geology, it is simply impossible, as every teacher knows, to avoid anticipations in one part of what strictly belongs to a subsequent part. It is for this reason that the order of presentation of the different departments, and

of the various subjects under each department, is so different in the hands of different writers. The order which I have adopted I know is not free from objection on this score, but it seemed to me, on the whole, the best.

In preparing the work I have, of course, drawn largely from many sources, both text-books and works of original research; for whatever of merit there be in a work of this kind must consist not so much in the novelty of the matter as in the selecting, grouping, and presentation. Such obligations are acknowledged in the pages of the work. I cannot forbear, however, making here a special acknowledgment of my indebtedness, in the historical part, to the invaluable manual of Prof. Dana. I must also acknowledge especial indebtedness to Profs. Marsh and Newberry, and the geologists and paleontologists of the United States Surveys, in charge of Prof. Hayden and Lieutenant Wheeler, not only for valuable materials, but also for much personal aid.

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INTRODUCTORY.

DEFINITION OF GEOLOGY, AND OF ITS DEPARTMENTS.

Geology is the physical history of the earth and its inhabitants, as recorded in its structure. It includes an account of the changes through which they have passed, the laws of these changes, and their causes. In a word, it is the *history of the evolution of the earth and its inhabitants.*

The fundamental idea of geology, as well as its principal subdivisions and its objects, may be most clearly brought out by comparing it with organic science. We may study an organism from three distinct points of view: 1. We may study its general form, the parts of which it is composed, and its minute internal structure. This is *anatomy.* It is best studied in the *dead* body. 2. We may study the *living* body in action, the function of each organ, the circulation of the fluids, and the manner in which all contribute to the complex phenomena of life. This is *physiology.* 3. We may study the living and *growing* body, by watching the process of *development* from the egg to the adult state, and striving to determine its laws. This is *embryology.*

So, looking upon the earth as an organic unit, we may study its form, the rocks and minerals of which it is composed, and the manner in which these are arranged; in other words, its external form and internal structure. This is the anatomy of the earth, and is called *structural geology.* Or, we may study the earth under the action of physical and chemical forces, the action and reaction of land and water, of earth and air, and the effects of these upon the form and structure. This is the physiology of the earth, and is called *dynamical geology.* Finally, we may study the earth in the progress of its development, from the earliest chaotic condition to its present condition, as the abode of man, and attempt to determine the laws of this development. This is the embryology of the earth, or *historical geology.*

Principal Departments.—The science of geology, therefore, naturally divides itself into three parts, viz.: 1. *Structural geology*, or geognosy. 2. *Dynamical geology*, or physical and chemical geology. 3. *Historical geology*, or the history of the earth.

But there are two important points of difference between geology and organic science. The central department of organic science is physiology, and both anatomy and embryology are chiefly studied to throw light on this. But the central department of geology, to which the others are subservient, is history. Again: in case of organisms—especially animal organisms—the nature of the changes producing development is such that the record of each previous condition is successively and entirely obliterated; so that the science of embryology is possible only by direct observation of each successive stage. If this were true also of the earth, a history of the earth would, of course, be impossible. But, fortunately, we find that each previous condition of the earth has left its record indelibly impressed on its structure.

Order of Treatment.—The prime object of geology is to determine the history of the earth, and of the organisms which have successively inhabited its surface. The structure and constitution of the earth are the *materials* of this history, and the physical and chemical changes now going on around us are the means of interpreting this structure and constitution. Evidently, therefore, the only logical order of presenting the facts of geology is to study, first, the causes, physical and chemical, *now* in operation and producing structure; then the structure and constitution of the earth which, *from the beginning*, have been produced by similar causes; and, lastly, from the two preceding to unfold the history of the earth.

Geology may be defined, therefore, as *the history of the earth and its inhabitants, as revealed in its structure, and as interpreted by causes still in operation.*

There is no other science which requires for its full comprehension a general knowledge of so many other departments of science. A knowledge of mathematics, physics, and chemistry, is required to understand dynamical geology; a knowledge of mineralogy and lithology is required to understand structural geology; and a knowledge of zoölogy and botany is required to understand the affinities of the animals and plants which have successively inhabited the earth, and the laws which have controlled their distribution in *time*.

PART I.

DYNAMICAL GEOLOGY.

THE agencies now in operation, modifying the structure of the surface of the earth, may be classed under four heads, viz., *atmospheric agencies*, *aqueous agencies*, *igneous agencies*, and *organic agencies.* These agencies have operated from the beginning, and are still in operation. We study their operation *now*, in order that we may understand their *effects* in previous epochs of the earth's history—i. e., the structure of the earth.

While all geologists agree that the *nature* of the agencies which have operated in modifying the earth's surface has remained the same from the beginning, they differ in their views as to the *energy* of their operation in different periods. Some believe that their energy has been much the same throughout the whole history of the earth, while others believe that many facts in the structure of the earth require much greater operative energy than now exists. We will attempt to show hereafter that neither of these extreme opinions is probably true, but that some of these agencies have been *decreasing*, while others have been *increasing*, with the progress of time. It is the constant change of balance between these which determines the development of the earth.

CHAPTER I.

ATMOSPHERIC AGENCIES.

THE general effect of atmospheric agencies is the disintegration of rocks and the formation of soils. The atmosphere is composed of nitrogen and oxygen, with small quantities of watery vapor and of carbonic acid. There are but few rocks which are not gradually disintegrated

under the constant chemical action of the atmosphere. The chemical agents of these changes are oxygen, carbonic acid, and watery vapor, the nitrogen being inert. To these must be added, where vegetation is present, the products of vegetable decomposition, especially ammonia *and humus acids.*[1]

Atmospheric agencies graduate so insensibly into aqueous agencies that it is difficult to define their limits. Water, holding in solution carbonic acid and oxygen, may exist as invisible vapor; or, partially condensed, as fogs; or, completely condensed, as rain falling upon and percolating the earth. In all these forms its chemical action is the same, and, therefore, cannot be separated and treated under different classes: and yet the same rain runs off from and erodes the surface of the earth, comes out from the strata and forms springs, rivers, etc., all of which naturally fall under aqueous agencies. We shall, therefore, treat of the *chemical* effects of atmospheric water in the *disintegration* of rocks, and *the formation of soils*, under the head of atmospheric agencies; and the *mechanical* effects of the same, in *eroding* the surface and *carrying away* the soil thus formed, under the head of aqueous agencies. In moist climates vegetation clothes and protects soil from erosion, but favors decomposition of rocks and formation of soil.

Atmospheric agencies are obscure in their operation, and, therefore, imperfectly understood. Yet these are not less important than aqueous agencies, since they are the necessary condition of the operation of the latter. Unless rocks were first disintegrated into soils by the action of the atmosphere, they would not be carried away and deposited as sediments by the agency of water. These two agencies are, therefore, of equal power and importance in geology, but they differ very much in the conspicuousness of their effects. Atmospheric agencies act almost equally at *all times* and at *all places*, and their effects, at any one place or time, are almost imperceptible. Aqueous agencies, on the contrary, in their operation are *occasional*, and to a great extent *local*, and their effects are, therefore, more striking and easily studied. Nevertheless, the aggregate effects of the former are equal to those of the latter.

Soils.—All soils (with the trifling exception of the thin stratum of vegetable mould which covers the ground in certain localities) are formed from the disintegration of rocks. Sometimes the soil is formed *in situ*, and, therefore, rests on its parent rock. Sometimes it is removed as fast as formed, and deposited at a distance more or less remote from the parent rock. The evidence of this origin of soils is clearest when the soil is formed *in situ*. In such cases it is often easy to trace every stage of gradation between perfect rock and perfect soil. This is well seen in railroad cuttings, and in wells in the gneissic or so-called *primary* region of our southern Atlantic slope. On examining such a

[1] Alexis Julien, "Proceedings of the American Association for the Advancement of Science," vol. xxviii., p. 311, *et seq.*

section, we find near the surface perfect soil, generally red clay; beneath this we find the same material, but lighter colored, coarser, and more distinctly stratified; beneath this, but shading into it by imperceptible gradations, we have what seems to be stratified rock, but it crumbles into coarse dust in the hand; this passes by imperceptible gradations into rotten rock, and finally into perfect rock. There can be no doubt that these are all different stages of a gradual decomposition. But closer observation will make the proof still clearer. In gneissic and other metamorphic regions it is not uncommon to find the rock traversed, in various directions, by veins of quartz or *flint*. Now, in sections such as those mentioned above, it is common to find such a flint-vein running through the rock and upward through the superincumbent soil, until it emerges on the surface. In the slow decomposition of the rock into soil, the flint-vein has remained unchanged, because flint is not affected by atmospheric agencies. Chemical analysis, also, always shows an evident relation between the soil and the subjacent or country rock, except in cases in which the soil has been brought from a considerable distance.

The *depth* to which soil will thus accumulate depends partly on the nature of the rock and the rapidity of decomposition, partly on the slope of the ground, and partly on climate. When the slope is considerable, as at *d* (Fig. 1), the rocks are bare, not because no soil is formed, but because it is removed as fast as formed, while at *a* the soil is deep, being formed partly by decomposition of rock *in situ*, and partly of soil brought down from *d*. Wherever perfect soil is found resting on sound rock, the soil has been shifted.

FIG. 1.—Ideal Section, showing Rock passing into Soil.

If rocks were solid and impervious to water, this process would be almost inconceivably slow; but we find that all rocks, for reasons to be discussed hereafter, are broken by fissures into irregular prismatic blocks, so that a perpendicular cliff of rock usually presents the appearance of rude gigantic masonry. These fissures, or *joints*, increase immensely the surface exposed to the action of atmospheric water. Again, on closer inspection, we find even the most solid parts of rocks, i. e., the blocks themselves, penetrated with *capillary fissures* which allow water to reach every part. Thus the rock is decomposed, or *becomes rotten*, to a great depth below the surface. But, while the rock is gradually changed into soil, the soil is also slowly carried away by agencies to be hereafter considered; and these changes, taking place more rapidly in

some places than in others, give rise to a great variety of forms, some of which are represented in the accompanying figure (Fig. 2).

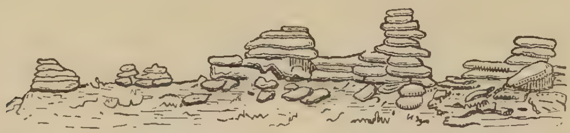


FIG. 2.

In the process of disintegration the original blocks lose their prismatic form, and become more or less rounded, and are then called *bowlders of disintegration*. These may lie on the surface (Fig. 2), or may be buried in the soil (Fig. 3). When of great size and very solid, so as to resist decomposition to a greater extent than the surrounding rocks, they often form huge *rocking-stones* (Fig. 4). These must not be confounded with true bowlders and rocking-stones which are brought from a distance, by agencies which we will discuss hereafter, and which are, therefore, entirely different from the subjacent or country rock.

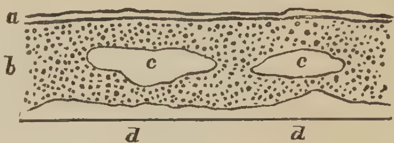


FIG. 3.

FIG. 4.

General Explanation.—The process of rock-disintegration may be explained, in a general way, as follows: Almost all rocks are composed partly of insoluble materials, and partly of materials which are slowly dissolved by atmospheric water. In the process of time, therefore, these latter are dissolved out, and the rock crumbles into an insoluble dust, more or less saturated with water holding in solution the soluble ingredients. To illustrate: common hardened mortar may be regarded as artificial stone; it consists of carbonate of lime and sand; the carbonate of lime is soluble in water containing carbonic acid (atmospheric water), while the sand is quite insoluble. If, therefore, such mortar be exposed to the air, it eventually crumbles into sand, moistened with water containing lime in solution. Again, to take a case which often occurs in Nature, it is not uncommon to find rock through which iron pyrites, FeS_2, is abundantly disseminated. This mineral is insoluble; but under the influence of water containing oxygen (atmospheric water) it is slowly oxidized and changed into *sulphate* of iron, or *copperas*, which, being soluble, is washed out, and the rock crumbles into an insoluble dust or soil, saturated with a solution of the iron salt. We

have given these only as illustrative examples. We now proceed to give examples of the principal kinds of rocks, and of the soils formed by their disintegration.

Granite, Gneiss, Volcanic Rocks, etc.—Granite and gneiss are mainly composed of three minerals, *quartz*, *feldspar*, and *mica*, aggregated together into a coherent mass. Quartz is unchangeable and insoluble in atmospheric water. Mica is also very slowly affected. Feldspar is, therefore, the decomposable ingredient. But feldspar is, itself, a complex substance, partly soluble and partly insoluble. It is essentially a silicate of alumina, united with a silicate of potash or soda, although it often contains also small quantities of iron and lime. Now, while the silicate of alumina is perfectly insoluble, the other silicates are slowly dissolved by atmospheric water, with the formation of carbonates, and the silicate of alumina is left as *kaolin or clay*. But, since we may regard the original rock as made up of quartz and mica, bound together by a cement of feldspar, the disintegration of the latter causes the whole rock to lose its coherence, and the final result of the process is a mass of clay containing grains of sand and scales of mica, and moistened with water containing a potash salt. If there be any iron in the feldspar, or if there be other decomposable ingredients in the rock containing iron, such, for example, as hornblende, the clay will be red. This is precisely the nature of the soil in all our primary regions. *Volcanic rocks* decompose into clay soils often, though not always, deeply colored with iron.

Limestone.—Pure limestone may be regarded as composed of granules of carbonate of lime, cohering by a cement of the same. The dissolving of the cement by atmospheric water forms a lime-soil, moistened with a solution of carbonate of lime (hard water). Impure limestone is a carbonate of lime, more or less mixed with sand or clay; by disintegration it forms, therefore, a *marly soil.*

Sandstones.—Sandstones consist of grains of sand cemented together by carbonate of lime or peroxide of iron. Where peroxide of iron is the cementing substance, the rock is almost indestructible, since this substance is not changed by atmospheric water: hence the great value of red sandstone as a building-material. But when carbonate of lime is the cementing material, this substance, being soluble in atmospheric water, is easily washed out, and the rock rapidly disintegrates into a sandy soil.

Slate.—In a similar manner *slate-rocks* disintegrate into a pure clay soil by the solution of their cementing material, which is often a small quantity of carbonate of lime.

There can be no doubt that all soils are formed in the manner above indicated. We have given examples of soils formed *in situ*, but, as soils are often shifted, they are usually composed of a mixture formed

by the disintegration of several kinds of rock. In some cases the soil has been formed *in situ* during the present geological epoch, and the process is still going on before our eyes. Such are the soils of the hills of the up-country or primary region of our Southern Atlantic States.[1] Sometimes the soil formed in the same way has been shifted to a greater or less distance. Such are the soils of our valleys and river-bottoms. In still other cases the soil has been formed by the process already described, and transported during some previous geological epoch and not reconsolidated. Such are many of the soils of the Southern low-country or tertiary region.

Mechanical Agencies of the Atmosphere.

Frost.—Water, penetrating rocks and freezing, breaks off huge fragments: these by a similar process are again broken and rebroken until the rock is reduced to dust. These effects are most conspicuous in cold climates and in mountain-regions. In cold climates huge piles of bowlders and earth are always seen at the base of steep cliffs (Fig. 5). Such a pile of materials, the ruins of the cliff above, is called a *talus*. In mountainous regions frost is a powerful agent in disintegrating the rocks, and in determining the outlines of mountain-peaks. This is well seen in the Alps and in the Sierras.

Fig. 5.

Winds.—The effect of winds is seen in the phenomenon of shifting sands. At Cape Cod, for instance, the sands thrown ashore by the sea are driven by the winds inland, and thus advance upon the cultivated lands, burying them and destroying their fertility. The sands from the beach on the Pacific coast near San Francisco are driven inland in a similar manner, and are now regularly encroaching upon the better soil. Large areas of the fertile alluvial soil of Egypt, together with their cities and monuments, have been buried by the encroachments of the Sahara Desert. The same phenomena are observed on various parts of the coast of France, Holland, and England. The rate of advance has been measured in some instances. Thus on the coast of Suffolk it is said to advance at the rate of about five miles a century; at Cape Finisterre, according to Ansted, at the rate of thirty-two miles per century, or 560 yards per annum. The Dunes of England and Scotland are such barrens of drifting sand. Hills may be formed in this manner thirty to forty feet in height. In the nearly rainless regions of the interior of our continent, high winds, laden with sand and gravel, are a powerful agent in sculpturing the rocks into the fantastic forms so often found there.[2]

[1] In the Northern States, in the region of the Drift, nearly all the soil has been shifted.

[2] Gilbert, "U. S. Geographical Surveys"—Lt. Wheeler in charge, vol. iii., Geology, p. 82.

CHAPTER II.

AQUEOUS AGENCIES.

The agencies of water are either *mechanical* or *chemical.* The mechanical agencies of water may be treated under the threefold aspect of *erosion*, *transportation*, and *sedimentary deposit.* We will consider them under the heads of *Rivers*, *Oceans*, and *Ice.* Under chemical agencies we will consider the phenomena of chemical deposits in *Springs* and *Lakes.*

Aqueous agencies.	Mechanical.	Rivers.......	Erosion,	Transportation,	Deposit.
		Ocean.......	"	"	"
		Ice..........	"	"	"
	Chemical.	Springs......	Deposit in.		
		Lakes.......	" "		

Section 1.—Rivers.

Under the head of river agencies we include all the effects of circulating metecric water from the time it falls as rain until it reaches the ocean: i. e., all the effects of *Rain and Rivers.*

Water, in the form of vapor, fogs, or rain, percolating through the earth, slowly disintegrates the hardest rocks. Much of these percolating waters, after accomplishing the work of soil-making, already treated in the preceding chapter, reappears on the surface in the form of springs, and gives rise to *streamlets.* A large portion of rain-water, however, never soaks into the earth, but runs off the surface, forming *rills*, which by erosion produce *furrows.* The uniting rills form *rivulets*, which excavate *gullies.* The rivulets, uniting with one another and with the streamlets issuing from springs, form *torrents*, which in their course excavate *ravines*, *gorges*, and *cañons.* The uniting torrents, finally issuing from their mountain-home upon the plains, form *great rivers*, which deposit their freight partly in their course and partly in the sea. Such is a condensed history of rain-water on its way to the ocean whence it came. Our object is to study this history in more detail.

Erosion of Rain and Rivers.

The whole amount of water falling on any land-surface may be divided into three parts: 1. That which rushes immediately off the surface, and causes the floods of the rivers, especially the smaller streams; 2. That which sinks into the earth, and, after doing its chemical work of soil-making, reappears as springs, and forms the regu-

lar supply of streams and rivers; and, 3. That which reaches the sea wholly by subterranean channels. Of these, the first two are the grand erosive agents, and these only concern us at present. Of these, the former predominate in proportion as the land-surface is bare; the latter in proportion as it is covered with vegetation.

Hydrographical Basin.—An hydrographical basin of a river, lake, or gulf, is the whole area of land the rainfall of which drains into that river, lake, or gulf. Thus the hydrographical basin of the Mississippi River is the whole area drained by that river. It is bounded on the east and west by the Alleghany and Rocky Mountains, and on the north by a low ridge running from Lake Superior westward. The whole area of continents, with the exception of rainless deserts, may be regarded as made up of hydrographical basins. The ridge which separates contiguous basins is called a *water-shed.* It is evident that every portion of the land, with the exception of the rainless tracts already mentioned, is subject to the erosive agency of water, and is being worn away and carried into the sea. There have been various attempts to estimate the *rate of this general erosion.*

Rate of Erosion of Continents.—This is usually estimated as follows: Some great river, such as the Mississippi, is taken as the subject of experiment. By accurate measurement *during every portion of the year*, the average amount of water discharged into the sea per second, per hour, per day, per year, is determined. This is a matter of no small difficulty, as it involves the previous determination of the average cross-section of the river and the average velocity of the current. The average cross-section $\times$ average velocity $=$ the average discharge per second: from which may be easily obtained the annual discharge. Next, by experiment during every month of the year, the average quantity of mud contained in a given quantity of water is also determined. By an easy calculation this gives us the annual discharge of mud, or the whole quantity of insoluble matter removed from the hydrographical basin in one year. This amount, divided by the area of the river-basin, will give the average *thickness of the layer of insoluble matter removed from the basin in one year.* To this must be added the soluble matters, which are about $\frac{1}{6}$ as much as the insoluble.

Estimates of this kind have been made for two great rivers, viz., the Ganges and the Mississippi. The whole amount of sediment annually carried to the sea by the Ganges has been estimated as 6,368,000,000 cubic feet. This amount, spread over the whole basin of the Ganges (400,000 square miles), would make a layer $\frac{1}{1751}$ of a foot thick. The Ganges, therefore, erodes its basin one foot in 1,751 years.[1] The area of the Mississippi Basin is 1,244,000 square miles. The annual discharge of sediment, according to the recent and accurate

[1] *Philosophical Magazine*, vol. v., p. 261.

experiments of Humphrey and Abbot, is 7,471,411,200 cubic feet, a mass sufficient to cover an area of one square mile, 268 feet deep.[1] This spread over the whole basin would cover it $\frac{1}{4640}$ of a foot. Therefore, this river removes from its basin a thickness of one foot in 4,640 years. The cause of the great difference in favor of the Ganges is, that this river is situated in a country subject to very great annual fall of water, the whole of which falls during a rainy season of six months. The rains are therefore very heavy, and the floods and consequent erosion proportionately great. The erosive power of this river is still further increased by the great slope of the basin, as it takes its rise in the Himalaya, the highest mountains in the world.

Now, since continents may be regarded as made up of hydrographical basins, the average rate of their erosion may be determined either by making similar experiments on all the rivers of the world, or, since this is impracticable, by taking some river as an average. We believe the Mississippi is much nearer an average river than the Ganges. It can hardly be less than the average, for a considerable portion of the earth —as rainless deserts—is not subject to any erosion. It is probable, therefore, that the whole surface of continents is *eroded at a rate not exceeding one foot in* 4,640 *years*. For convenience, we will call it one foot in 5,000 years. We will use this estimate when we come to speak of the actual erosion which has occurred in geological times.

Law of Variation of Erosive Power.—The *erosive power* of water, or its *power of overcoming cohesion, varies as the square of the velocity of the current* ($p \propto v^2$). The *velocity* depends upon the slope of the bed, the depth of the water, and many other circumstances, so numerous and complicated that it has been found impossible to reduce it to any simple law. The angle of slope, however, is evidently the most important circumstance which controls velocity, and therefore erosive power. In the upper portions of great rivers, like the Mississippi, the erosion is very great; while in the plains near the mouth there may be no erosion, but, on the contrary, sedimentary deposit. The high lands therefore, especially mountain-chains, are the great theatres of erosion. The *general* effect of erosion is *leveling*. If unopposed, the final effect would be to cut down all lands to the level of the sea, at an average rate of about one foot in 5,000 years. But the immediate *local* effect is to increase the inequalities of land-surface, deepening the furrows, gullies, and gorges, and increasing the intervening ridges and peaks. The effect, therefore, is like that of a graver's tool, constantly cutting at every elevation, but making trenches at every stroke.

Thus land-surfaces everywhere, especially in mountain-regions, are cut away by a process of sculpturing, and the *débris* carried to the lowlands and to the sea. The smaller lines and more delicate touches are

[1] Humphrey and Abbot, "Report on Mississippi River," pp. 148–150.

due to *rain*, the deeper trenches or heavier chiselings to rivers proper. The effects of the former are more *general* and far *greater* in the aggregate, but the effects of the latter are far more conspicuous. It is only under certain conditions that rain-sculpture becomes conspicuous. These conditions seem to be a bare soil and absence of frost. Beautiful examples are found in the arid regions of Southern Utah.

We now proceed to discuss the more conspicuous effects of water concentrated in river-channels.

Examples of Great Erosion now going on: Waterfalls.

The erosive power of water is most easily studied in ravines, gorges, cañons, and especially in great waterfalls. One of the most interesting of these is Niagara.

Niagara: General Description.—The plateau on which stands Lake Erie (*P N*, Fig. 6) is elevated about 300 feet above that of

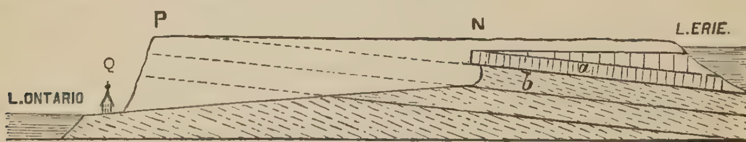


Fig. 6.—Ideal Longitudinal Section through Niagara River from Lake Erie to Lake Ontario.

Lake Ontario, and is terminated abruptly by an escarpment about 300 feet high (*P*). From this point a narrow gorge with nearly perpendicular sides, and 200 to 300 feet deep, runs backward through the higher or Erie plateau as far as the falls (*N*). The Niagara River runs out of Lake Erie and upon the Erie plateau as far as the falls, then pitches 167 feet perpendicularly, and then runs in the gorge for seven miles to Queenstown (*Q*), where it emerges on the Ontario plateau. Long observation has proved that the position of the fall is not stationary, but slowly recedes at a rate which has been variously estimated from one to three feet per annum. The process of recession has been carefully observed, and the reason why it maintains its perpendicularity is very clear. The surface-rock of Erie plateau is a firm limestone (*a*). Beneath this is a softer shale (*b*). This softer rock is rapidly eroded by the force of the falling water, and leaves the harder limestone projecting as *table-rocks*. From time to time these projecting tables are loosened and fall into the chasm below. This process is facilitated by the joint structure spoken of on page 5.

Recession of the Falls.—Now, there is every reason to believe that the fall was originally situated at Queenstown, the river falling over the escarpment at that place, and that it has worked its way backward seven miles to its present position by the process we have just described. These reasons are as follows: 1. The general configuration of the country

as already described forcibly suggests such an explanation to the most casual observer. 2. A closer examination confirms it by showing that the gorge is truly *a valley of erosion*, since the strata on the two sides correspond accurately (*see* Fig. 7). 3. As already seen, the falls have receded in historic times at a rate, according to Mr. Lyell, of about one foot a year. The portion of the gorge thus formed under our eyes does not differ in any essential respect from other portions farther down the stream. The evidence thus far is not perfectly conclusive that the gorge was formed by the *present river* during the *present geologic epoch*, since the gorge may have been eroded during a previous epoch, and the present river found it, appropriated it as its channel, and continued to extend it. But (4.) certain stratified deposits have been found by Mr. Lyell and others on the upper margin of the ravine, containing shells, all of which are identical with the shells now living in Niagara River. On the margins of all rivers we find stratified deposits of mud and sand containing dead shell. The stratified deposits found by Mr. Lyell were such mud-banks of the Niagara River before the falls had receded so far, and therefore when the river still ran on the Erie plateau at this point. This is well seen in the subjoined figure, representing an ideal

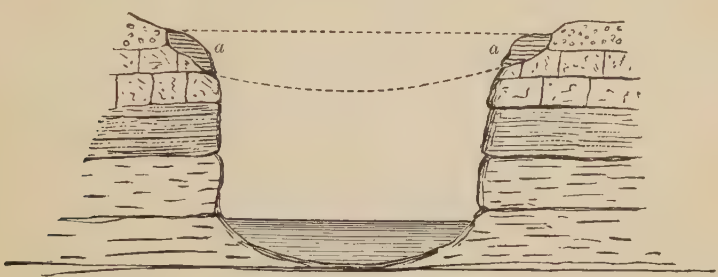


FIG. 7.—Ideal Section across Chasm below the Falls.

cross-section of the gorge below the falls. The dotted lines represent the former bed and level of the river; *a a* represent the banks of stratified mud left on the margin of the gorge, as the river eroded its bed down to its present level.

Other Falls.—The evidence is completed by examination of other great falls. In almost all perpendicular falls we find a similar arrangement of strata followed by similar results. The Falls of St. Anthony, in the Mississippi River, are a very beautiful illustration. Here we find a configuration of surface very similar to that in the neighborhood of Niagara. Above the falls the Mississippi River runs on a plateau which terminates abruptly at the mouth of Minnesota River by an escarpment some fifty feet high. From this escarpment, backward through the upper plateau, runs a gorge with perpendicular sides fifty feet high for

ten miles to the foot of the falls. The river above the falls runs on a hard, silurian limestone rock, only a few feet in thickness. Beneath this is a white sandstone, so soft that it can be easily excavated with the fingers. This sandstone forms the walls of the gorge as far as the escarpment. The recession of the falls by the undermining and falling of the limestone is even more evident than at Niagara. Tributaries running into the Mississippi just below the falls are, of course, precipitated over the margin of the gorge. Here, therefore, the same conditions are repeated, and hence are formed subordinate gorges, headed by perpendicular falls. Such are the falls and gorge of Little River (Minnehaha), which runs into the Mississippi about three miles above the mouth of the Minnesota River.

Another admirable illustration of the conditions under which perpendicular falls recede is found in the falls of the numerous tributaries of Columbia River where the great river breaks through the Cascade Range. The Columbia River gorge is 2,500 to 3,000 feet deep. The walls consist of columnar basalt underlaid near the water-level by a softer conglomerate. Every tributary at this point emerges from a deep gorge, headed two or three miles back by a perpendicular wall, over which is precipitated the water of the tributary as a fall 200 to 300 feet high. The falling water erodes the softer conglomerate, undermines the vertical-columned basalt, which tumbles into the stream and is carried away; and thus the fall has worked back in each case about two or three miles to its present position.[1] All of this has taken place during the present geological epoch.[2]

The wonderful falls of the Yosemite Valley, of which there are six in a radius of five miles, one of them 1,600 feet, three 600 to 700 feet, and two over 400 feet high, seem to be an exception to the law given above. Their perpendicularity seems to be the result of the *comparative recency* of the evacuation of the valley by an ancient glacier, and therefore the shortness of the time during which the rivers have been falling, combined with the hardness of the granite rocks. The Yosemite gorge was not made by the present rivers.

Time necessary to excavate Niagara Gorge.—All attempts to estimate *accurately* the time consumed in excavating Niagara gorge must be unreliable, since we do not yet know the circumstances which controlled the rate of recession at different stages of its progress. Among these circumstances, the most important are the volume of water, and especially the hardness of the rocks, and the manner in which hard and

[1] Gilbert has shown (*American Journal*, August, 1876) that comparative freedom from detritus is another condition of the formation of perpendicular waterfalls. In muddy rivers commencing inequalities are filled up by sediment, and waterfalls cannot be formed.

[2] *American Journal of Science and Art*, 1874, vol. vii., pp. 167, 259.

soft are superposed. The present position of the falls is apparently favorable for rapid recession. Mr. Lyell thinks, from personal observation, that the average rate could not have been more than one foot per annum, and probably much less. At this rate, it would require about 36,000 years. But, whether more or less than this amount, this period must not be confounded with the age of the earth. The work of excavating the Niagara chasm belongs to the present epoch, and the time is absolutely insignificant in comparison with the inconceivable ages of which we will speak in the subsequent parts of this work. The falls of St. Anthony recedes about five feet per annum, and has made its gorge in about 8,000 years (Winchell).

Ravines, Gorges, Cañons.—We have already seen (page 11) that ravines, gorges, etc., are everywhere produced in mountain-regions by the regular operation of erosive agents. Nowhere are examples more abundant or more conspicuous than in our own country, and especially in the Western portion. On the Pacific slope, the most remarkable are the gorges of the *Fraser* and of the *Columbia* Rivers, fifty miles long and several thousand feet deep; those of the North and South Forks of the *American* River, 2,000 to 3,000 feet deep in solid slate; the cañon of the *Tuolumne* River with its *Hetchhetchy* Valley; the cañon of the *Merced*, with its *Yosemite* Valley, with nearly vertical granite cliffs, 3,000 to nearly 5,000 feet high; and, deepest of all, the *grand cañon of King's* River, 3,000 to 7,000 feet deep, in hard granite.

Some of these great cañons have been forming ever since the formation of the Sierra Range—i. e., since the Jurassic period. It is possible, also, that in some of them the erosive agents have been *assisted* by antecedent igneous agencies, producing fissures, which have been enlarged and deepened by water and by ice. But there are some, at least, which may be proved to have been produced wholly by erosion, and that during the present or at least during very recent geological times. We refer especially to those which have been cut through lava-streams.

In Middle and Northern California are found lava-streams which have flowed from the crest of the Sierra. By means of the strata on which they lie, these streams are known to have flowed after the end of the Tertiary period. Yet the present rivers have since that time cut

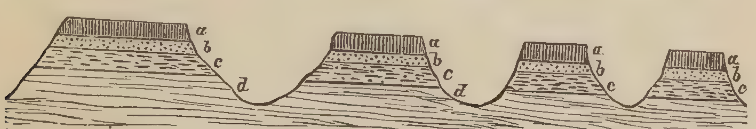


FIG. 8.—Lava-Stream cut through by Rivers: *a a*, Basalt; *b b*, Volcanic Ashes; *c c*, Tertiary; *d d*, Cretaceous Rocks. (From Whitney.)

great cañons through the lava and into the underlying rock, in some cases at least 2,000 feet deep. Such facts impress us with the immen-

sity of geological times. This important point is discussed more fully in a subsequent part of this work.

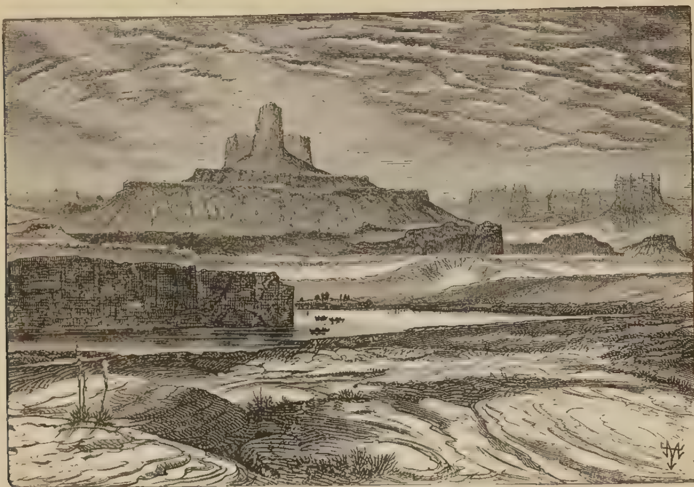


FIG. 9.—Buttes of the Cross (Powell).

But nowhere in this country, or in the world, are the phenomena of cañons exhibited on so grand a scale, and nowhere are they so obviously

FIG. 10.—Cañon of the Colorado and its Tributaries (from a Drawing by Newberry).

the result of pure erosion, as in the region of the Grand Plateau of Utah, Arizona, New Mexico, and Colorado. This plateau is elevated 7,000 to 8,000 feet above the sea, and composed entirely of nearly horizontal strata, comprising nearly the whole geological series from the Tertiary downward. Through this series all the streams have cut their way downward, forming narrow cañons with almost perpendicular walls several thousand feet deep, so that in many parts we have the singular phenomenon of a whole river-system running almost hidden far below the surface of the country, and rendering the country entirely impassable in certain directions (*see* Frontispiece). Nor is the erosion confined to cañons; for the rain-erosion has been so thorough and general that much of the upper portion of the plateau has been wholly carried away, leaving only isolated turrets (*buttes*) or isolated level tables with cliff-like walls (*mesas*) to indicate their original height. All these facts are well shown in Fig. 10. The explanation of these deep and narrow cañons is probably to be found in the predominance of stream-erosion over general disintegration and rain-erosion, which is characteristic of an arid climate (Gilbert).

Chief among these cañons is the *Grand Cañon* of the Colorado, 300 miles long and 3,000 to 6,200 feet deep, forming the grandest natural geological section known. Into this the tributaries enter by side-cañons of nearly equal depth, and often of extreme narrowness. Fig. 11 represents the natural proportions of such a cañon.

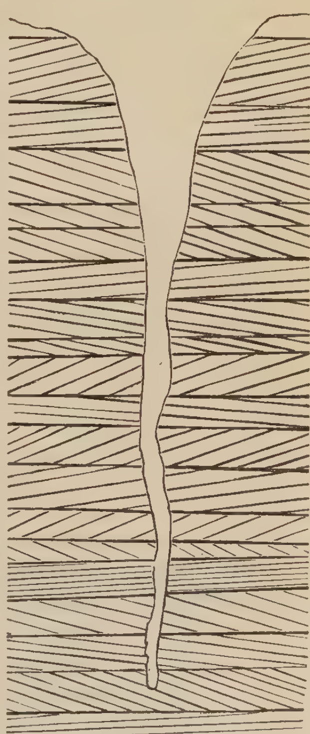


Fig. 11.—Section of the Virgen River (after Gilbert).

Time.—These remarkable cañons have evidently been cut wholly by the streams which now occupy them, and which are still continuing the work. The work, probably commenced in the early Tertiary with the emergence of this portion of the continent, became more rapid in the latter portion of the Tertiary with the great elevation of the plateau, and has continued to the present time. Thus, causes now in operation are identified with geological agencies.

In the Appalachian chain gorges and valleys of erosion are abundant, but the evidences of present action are less obvious, and therefore we defer their treatment to Part II., for we are now discussing *agencies still in operation.* Among

the more remarkable narrow gorges in this region, we may mention, in passing, the *Tallulah* River gorge, several miles long and nearly 1,000 feet deep, in Rabun County, Georgia, and the gorge of the *French Broad* in North Carolina. The general effects of erosion will be more fully treated under "Mountain Sculpture" (page 255).

Transportation and Distribution of Sediments.

The specific gravity of most rocks is about 2.5. Immersed in water, they, therefore, lose nearly half their weight. This fact greatly increases the transporting power of water. The actual transporting power of water is determined partly by experiment and partly by reasoning on the general laws of force. By experiment we determine the transporting power under a given set of circumstances: by general reasoning we determine its law of variation, and apply the data given by experiment to every possible case.

Experiments.—It has been found by experiment that a current, moving at the rate of three inches per second, will take up and carry along *fine clay;* moving six inches per second, will carry *fine sand;* eight inches per second, *coarse sand*, the size of linseed; twelve inches, gravel; twenty-four inches, pebbles; three feet, angular stones of the size of a hen's-egg.[1] It will be readily seen from the above that the *carrying-power increases much more rapidly than the velocity.* For instance, a current of twelve inches per second carries gravel, while a current of three feet per second, only three times greater velocity, carries stones many hundred times as large as grains of gravel. Let us investigate the *law.*

Law of Variation.—If the surface of the obstacle is constant, the force of running water varies as the velocity squared: $f \propto v^2$ (1). This may be easily proved. Suppose we have an obstacle like the pier of a bridge, standing in water running with any given velocity. Now, if from any cause the velocity of the current be *doubled*, since momentum or force is equal to quantity of matter multiplied by velocity ($M = Q \times V$), the force of the current will be *quadrupled*, for there will be double the quantity of water striking the pier in a given time with double the velocity. If the velocity of the current be trebled, there will be three times the quantity of matter striking with three times the velocity, and the force will be increased nine times. If the velocity be quadrupled, the force is increased sixteen times, and so on.

Next, if the velocity of the current remains constant, while the size of the opposing obstacle varies, then evidently the force of the current will vary as the *opposing surface:* if the opposing surface is doubled, the force is doubled; if trebled, the force is trebled, etc. But in similar figures, surfaces vary as the square of the diameter. Therefore, in this case, force varies as diameter squared: $f^1 \propto d^2$ (2). Therefore, when

[1] Page's "Geology," p. 28—Rankine.

both the velocity of the current and the size of the stone or other obstacle *vary*, then the force varies as the square of the velocity of the current multiplied by the square of the diameter of the stone: $F \propto v^2 \times d^2$ (3).

This last equation gives the law of variation of the *moving force*. But the *resistance* to be overcome, or the *weight* of the stone, varies as the cube of the diameters: $W \propto d^3$. We have, therefore, both the law of the moving force and the law of the resistance: $\begin{cases} F \propto v^2 \times d^2. \\ W \propto d^3. \end{cases}$

Now the case we wish to consider is that in which *the current is just able to move the stone*, or when $F \propto W$. In this case $d^3 \propto v^2 \times d^2$, or $d \propto v^2$. Substituting, in the third equation, for d its value, $F \propto v^2 \times v^4 = v^6$. We place these equations together, so that they may be better understood:

When surface = constant . . .	$f \propto v^2$ (1)
When velocity = constant . . .	$f^1 \propto d^2$ (2)
When both vary	$F \propto v^2 \times d^2$ (3)
But	$W \propto d^3$
And when $W \propto F$, then	$d^3 \propto v^2 \times d^2$
Dividing by d^2	$d \propto v^2$
Substituting in 3	$F \propto v^2 \times v^4$
Or	$F \propto v^6$

That is, *the transporting power of a current varies as the sixth power of the velocity*. This seems so extraordinary a result that, before accepting it, we will try to make it still clearer by an example.

Let a (Fig. 12) represent a cubic inch of stone, which a current of a certain velocity will just move. Now, the proposition is that, if the velocity of the current be doubled, it will move the stone b, sixty-four times as large. That it would do so is evident from the fact that the opposing surface of b is sixteen times as great as that of a, and the moving force would be increased sixteen times from this cause. But the velocity being double, as we have already seen, the force against every square inch of b will be four times that against a, and, therefore, the whole force from these two causes would be $16 \times 4 = 64$ times as great. But the weight is also sixty-four times as great; therefore, the current would be just able to move it. We may accept it, therefore, as a law, that the transporting power varies as the sixth power of the velocity. If the velocity, therefore, be increased ten times, the transporting power is increased 1,000,000 times.

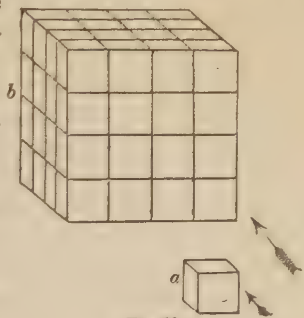


FIG. 12.

We have seen that a current running three feet per second, or about two miles per hour, will move fragments of stone of the size of a hen's-egg, or about three ounces' weight. It follows from the above law that a current of ten miles an hour will bear fragments of one and a half ton, and a torrent of twenty miles an hour will carry fragments of 100 tons' weight. We can thus easily understand the destructive effects of mountain-torrents when swollen by floods.

The *transporting* power of water must not be confounded with its *erosive* power. The resistance to be overcome in the one case is *weight*, in the other *cohesion;* the latter varies as the *square*, the former as the *sixth power* of the velocity. In many cases of removal of slightly cohering material the resistance is a mixture of these two resistances, and the power of removing material will vary at some rate between v^2 and v^6.

There are certain corollaries which follow from the above law:

A. If a current bearing sediment have its velocity checked by any cause, even in a slight degree, a comparatively large portion of the sediment is immediately deposited. But if, on the other hand, the velocity of a current be increased by any cause, in never so small a degree, it will again take up and carry on materials which it had deposited; in other words, it will erode its bed and banks; and these effects are surprisingly large on account of the great change in erosive and transporting power, with even slight changes of velocity.

B. Water, whether still or running, has a wonderful power of *sorting* materials. If heterogeneous material, such as ordinary earth, consisting of grains of all sizes, from pebbles to the finest clay, be thrown into *still water*, the coarse material sinks first to the bottom, and then the next finer, and the next, and so on, until the finest clay, falling last, covers the whole. In *running water* the same sorting takes place even more perfectly, only the different kinds of materials are not dropped upon one another, but successively farther and farther down the stream in the order of their fineness. This property we will call the *sorting power of water*. Advantage is often taken of this property in the arts to separate materials of different sizes or specific gravities. By this means grains of gold are separated from the gravel with which it is mingled, and emery or other powders are separated into various degrees of fineness.

We will now apply the foregoing simple principles in the explanation of all the phenomena of currents.

1.—*Stratification.*

We have seen that heterogeneous material thrown into still water is completely sorted. This is not stratification, since the various degrees of fineness graduate insensibly into one another. But if we repeat the experiment, the coarsest material will fall upon the finest of the previous experiment, and then graduate similarly upward. If we examine the

deposit thus made, we observe a distinct line of junction between the first and the second deposit. This is *stratification*, or lamination. For every repetition of the experiment a distinct lamina is formed. It is evident, therefore, that to produce stratification two conditions are necessary, namely: 1. An heterogeneous material; and, 2. An intermittently-acting cause. Now, these two conditions are always present in Nature where sediments are depositing. Into every body of *still water*, as a lake or sea, rivers bring heterogeneous material torn from the land; but this process is not equable, being increased in the case of small streams by every rain, and in large rivers by the annual floods. Therefore, sedimentary deposits in still water are always stratified.

In *running water* the case is somewhat different. If the stream runs with a velocity at all times the same, then with every repetition of the foregoing experiment the same kind of material falls on the same spot—gravel on gravel, sand on sand, and mud on mud—and there will be no stratification. In running water, therefore, another condition is necessary, namely, a *variable current*. For, when the velocity increases, coarser material will be carried and deposited where finer was previously deposited; when the velocity decreases, finer will be deposited on coarser, and very perfect stratification is the result. Now, these three conditions are always present in every natural current. The velocity of every river-current varies not only very greatly in different portions of the year, as in seasons of low water and seasons of flood, but also (from the constant shifting of the subordinate currents of the stream) from day to day, from hour to hour, and even from moment to moment. It follows, therefore, that deposits in running water are also always stratified. Sometimes extreme beauty and distinctness of stratification in the deposits of large rivers are due to the fact that the different branches flood at different seasons, and bring down differently-colored sediments.

We may, therefore, announce it as a law, that *all sedimentary deposits are stratified;* and, conversely, that *all stratified masses in which the stratification is the result of sorted material are sedimentary in their origin.* Upon this law is founded almost all geological reasoning.

2.—*Winding Course of Rivers*

The winding course of rivers is due partly to erosion, and partly to sedimentary deposit. It is most conspicuous and most easily studied in rivers which run through extensive alluvial deposit. If the channel of such a river be made perfectly straight by artificial means, very soon some portion of the bank a little softer than the rest will be excavated; this will reflect the current obliquely across to the other side, which will become similarly excavated. Thus the current is reflected from side to side, increasing the excavations. In the mean time, while erosion is progressing on the outer side of the curves, because the current

is swiftest there, deposit is taking place on the inner side, because there the current is slowest; thus, while the outer curve extends by erosion, the inner curve extends, *pari passu*, by deposit (Fig. 13), and the winding continues to increase, until, under favorable circumstances, contiguous curves on the same side run into each other, as at *a b*, and the curve *c* on the other side is thrown out and silted up. Thus are formed the crescentic lakes, or *lagoons* (*l l*), so common in the swamps of great rivers. They are abundant in the swamps of all the Gulf rivers, especially the Mississippi. They are *old beds of the river*, thrown out and silted up in the manner indicated above.

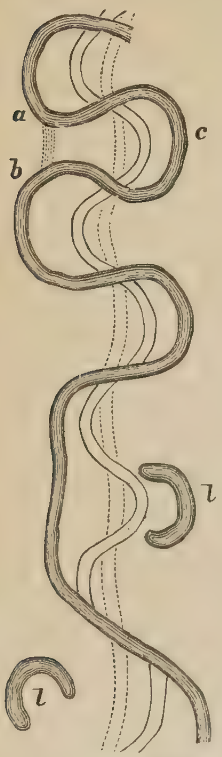


FIG. 13.—Three Successive Stages of a Meandering River.

3.—*Flood-Plain Deposits.*

All great rivers annually flood portions of level land near their mouths, and cover them with sedimentary deposits. The whole area thus flooded is called the *flood-plain*. These flood-plains are very extensive, and the deposits very large, in the case of rivers rising in lofty mountains and flowing in the lower portion of their course through extensive tracts of flat country. In the lofty mountains the current runs with great velocity, and gathers abundant sediment; on reaching the flat country the velocity is checked, the river overflows, and the sediment is deposited. The flood-plain of the Mississippi River is 30,000 square miles. The flood-plain of the Nile is the whole land of Egypt.

The flood-plain of a river may be divided into two parts, viz., the river-swamp and the delta. The river-swamp is that part which was originally land-surface; the delta that part which has been reclaimed from the sea or lake by the river. We will take up these in succession.

River-Swamp.—We have already seen that, with every recurrence of the rainy season or of the melting of snows, the flooding and the deposition of sediment are repeated. Thus the river-swamp deposit increases in thickness, and the level of the whole flood-plain rises continually. Fig. 14 is an ideal section showing the manner in which the flood-plain is successively built up; *a a a* is the supposed original configuration of the surface, *b b* the successive levels of deposit, *e* the level of the river at low water, and *i i* the level of flood-water.

The extent of such river-swamp deposits is sometimes very great. The river-swamp of the Nile constitutes the whole fertile land of Egypt

above the delta. The river-swamp of the Mississippi River, or its flood-plain exclusive of the delta, extends from fifty miles above the mouth of the Ohio to the head of the delta, a distance of about 700 miles; its width is ten to fifty miles, and it includes an area of 16,000

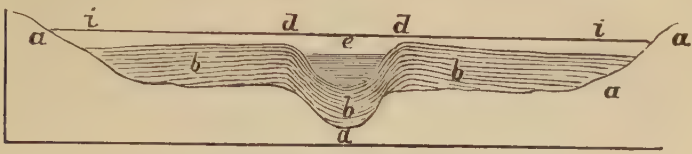


FIG. 14.—Ideal Section of a River subject to Floods.

square miles. It is bounded on either side by high bluffs belonging to a previous geological period. The depth of this deposit at the head of the delta is assumed by Lyell to be 264 feet.[1] But Hilgard has shown that but a small portion of this is actually river deposit.

Natural Levées.—It is seen by the cross-section (Fig. 14) that the level of the river-swamp slopes gently from the river outward, so that the river is bounded on each side by a higher ridge, *d d*. The material of this ridge is coarser than that of the swamp farther back. Such *natural levées* are found along all rivers subject to regular overflows. They are formed as follows: In times of flood the whole flood-plain is covered with water moving slowly seaward. Through the midst of this wide expanse of water runs the rapid current of the river. Now, on either side, just where the rapid current of the river comes in contact with the comparatively still water of the flood-plain, and is checked by it, a line of abundant sediment is determined, which forms the natural levée. Except in very high freshets, these natural ridges are not entirely covered, so that the river in ordinary floods is often divided into three streams, viz., the river proper and the river-swamp water on either side. They cannot, however, confine the river within its bank and prevent overflows, since the river-bed is also constantly rising by deposit. Thus the river-bed, the natural levée, and the river-swamp, all rise together, maintaining a certain constant relation to one another.

Artificial Levées.—This constant relation is interfered with by the construction of artificial levées. These are constructed for the purpose of confining the river within its banks, and thus reclaiming the fertile lands of the river-swamp. As the bed of the river continues to rise by deposit, the levées must be constantly elevated in proportion; but the river-swamp, being deprived of its share of deposit, does not rise. Thus, under the combined effect of human and river agencies contending for mastery, an ever-increasing embankment is formed, until finally the river runs in an aqueduct elevated far above the surrounding plain.

[1] Lyell, "Principles of Geology," vol. i., p. 462.

This is very remarkably the case with the river Po, which is said to run in a channel that has been thus elevated above the tops of the houses in the town of Ferrara. Fig. 15 is an ideal cross-section of a river and

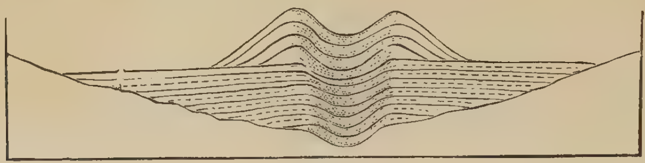


FIG. 15.

flood-plain, left at first to the action of natural causes for a time, but afterward interfered with by the construction of artificial levées. The dotted strata show the work of Nature, and the undotted the work of man. It is easy to see that the destructive effects of overflow from accidental crevasses become greater and greater with the elevation. The Po has thus several times broken through its levées and deserted its bed, destroying several villages. The best examples of rivers successfully levéed are those of Italy and Holland. The Mississippi has never been successfully levéed; but if it should be, it would commence to build up a similar aqueduct, until the whole bed of the river would finally rise above the level of the river-swamp.[1]

4.—*Deltas.*

Deltas are portions of land situated at the mouths of rivers, and *reclaimed from the sea by their agency.* Over the flat surface of the delta the river runs by inverse ramification, and empties by many mouths. They are usually of irregular triangular form, the apex of the triangle pointing up the stream. The delta of the Nile (Fig. 16) is perhaps the best example of the typical form. As seen in the figure, at the head of the delta the river divides into branches, and communicates with the sea by many mouths. The area of land thus made varies with the size of the river, the proportion of sediment in its waters, and the time it has been making sedimentary accumulations. The delta of the Nile is 100 miles long and 200 miles wide at its base; that of the Ganges and Brahmapootra is 220 miles long and 200 miles wide at its base, comprising an area of 20,000 square miles. The delta of the Mississippi (Fig. 17) is very irregular in form, and is an admirable illustration of the manner in which each mouth pushes its way into the sea. Its area is estimated at 12,300 square miles. The materials

[1] It is probable that the effect of levées in raising the river-bed has been greatly exaggerated. Recent observations on the Po seem to show that the elevation is confined to the upper reaches of the flood-plain region, being prevented in the lower course by the increased velocity of the current produced by levées.

FIG. 16.—Delta of the Nile.

of which deltas are composed are usually the finest sands and clays, all the coarser materials having been deposited higher up the stream.

Deltas are formed only in *lakes* and *tideless* or nearly *tideless seas.*

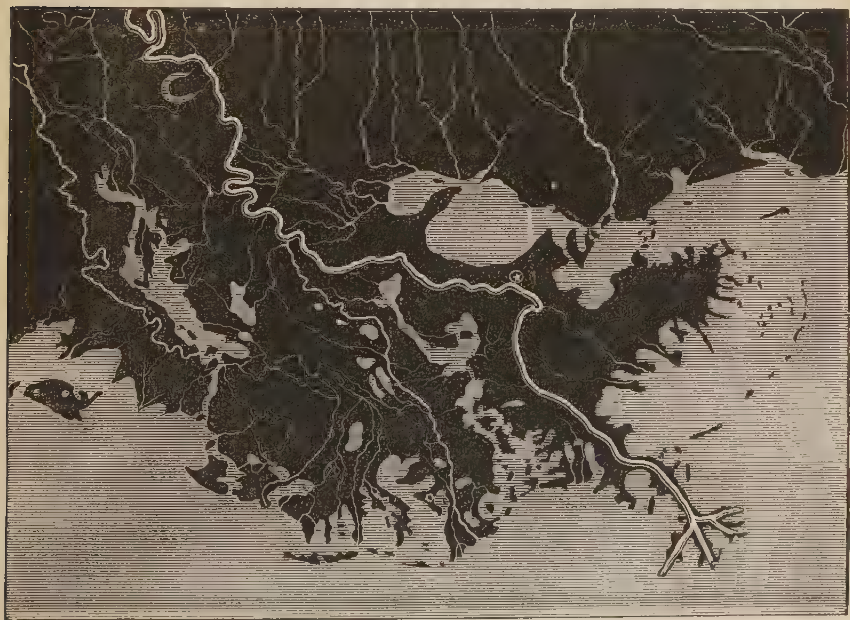


FIG. 17.—Delta of the Mississippi.

In tidal seas, the sediments brought down by the rivers are swept away and carried to sea by the retreating tide; and instead of the land encroaching upon the domain of the sea by the formation of deltas, the sea encroaches upon the land by the erosive action of the tides, and forms bays or *estuaries.* Thus in tideless seas or lakes the rivers empty by many slender mouths, while in tidal seas they empty by wide bays; thus, for example, all the rivers emptying into the great Canadian lakes, and all the rivers emptying into the Gulf of Mexico, form deltas, while all the rivers emptying into the Atlantic in both North and South America form estuaries. In Europe all the rivers emptying into the Black, the Caspian, the Mediterranean, and the Baltic, form deltas, while those emptying into the Atlantic form estuaries.

Process of Formation.—The process of formation of a delta may be best studied by observing it on a small scale, in the case of streamlets running into ponds. In such cases we observe always a sand or mud flat at the mouth of the streamlet, evidently formed by the sand and clay brought down by the current. As soon as the current strikes the still water of the pond, its velocity is checked, and its burden of sediment is deposited. Through the sand-flat thus formed the streamlet ramifies, as seen in Fig. 18. The ramification seems to be the result of the choking of the stream by its own deposit, which forces it to seek new channels. The sand-flat is gradually extended farther and farther into the pond by successive deposits, as shown in Fig. 18. Fig. 19 shows

Fig. 18.

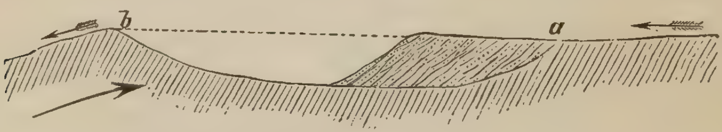


Fig. 19.

the irregular stratified appearance of the deposit as seen on cross-section. In all such cases of streams flowing into ponds or lakes, the stream flows *in* at *a* muddy, but flows *out* at *b* perfectly clear, having deposited all its sediment in the pond or lake. Evidently if this process continues without interruption, the pond will eventually be filled up, after which, of course, the sediment will be carried farther down the stream. In this manner small mountain-lakes are often entirely filled up. The Rhône flows into Lake Geneva a turbid stream, but flows out beautifully transparent. The whole of its sediment is de-

posited where it enters the lake, and it has there formed a delta six miles long. We may confidently look forward to the time, though many thousand years distant, when this lake will be entirely filled up. After leaving the lake the Rhône again gathers sediment from tributaries flowing in below the lake, and forms another delta where it empties into the Mediterranean. Many examples of lakelets partially filled, or entirely filled and converted into meadows, are found among the Sierra Mountains.

In the section view (Fig. 19), we have represented the strata as irregular and highly inclined. This is called *oblique lamination.* This can only occur when a rapid stream, bearing abundant *coarse material*, rushes into still water. But in the case of large rivers flowing long distances and bearing only the finest sediment, the stratification is much *more regular* and *nearly horizontal.*

Rate of Growth.—There have been several attempts to estimate the rate of growth of deltas, in order to base thereon an estimate of their age. The delta of the Rhône in Lake Geneva has advanced at least one and a half mile since the occupation of that country by the Romans; for the ancient town Porta Valesia (now Port Valais), which stood then on the margin of the lake, is now one and a half miles inland. The delta of the same river at its mouth in the Mediterranean is said to have advanced twenty-six kilometres, or sixteen miles, since 400 B. C., or thirteen miles during the Christian era.[1] The delta of the Po has advanced twenty miles since the time of Augustus; for the town Adria, a seaport at that time, is now twenty miles inland. But the most elaborate observations have been made on the Mississippi. This river, as seen in Fig. 17, has pushed its way into the Gulf in a most extraordinary manner. According to Thomassy,[2] and also Humphrey and Abbot, the rate of advance is about one mile in sixteen years. The rate of progress in the deltas mentioned has, however, probably not been uniform. There are special reasons for their more rapid advance at the present time. In the case of the Po, the successful levéeing of this river has transferred to the sea the whole of the sediment which would otherwise have been spread over the flood-plain. In the case of the Mississippi, for many centuries the principal portion of the deposit has been confined to a narrow strip but a few miles wide, and the advance has been proportionately rapid. For this reason the river has run out to sea for more than fifty miles, confined only by narrow strips of land, *the continuation of the natural levées.* These marginal ridges are continued as submarine banks even much beyond the present mouths of the river. The rate of advance of the Nile delta seems to be much slower.

Age of River-Deposits.—The age of *river-swamp* deposits may be

[1] "Archives des Sciences," vol. li., p. 157. [2] "Géologie pratique de la Louisiane."

estimated by determining their absolute thickness and their rate of increase. The river Nile is peculiarly adapted for estimates of this kind, because we have on its alluvial deposits the seat of the oldest civilization and the oldest known monuments of human art. These monuments, the ages of which are approximately known, are many of them more or less buried in the river-deposit. At Memphis, the

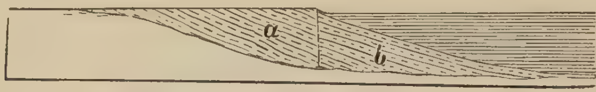


FIG. 20.—Ideal Section of Delta and Submarine Bank.

foundation of the colossal statue of Rameses II., over 3,000 years old, was found in 1854 buried about nine feet in river-deposit.[1] This makes the rate of increase of the deposit three and a half inches per century. Experiments at Heliopolis bring out nearly the same result. The whole depth of the alluvial deposit at Memphis was found to be about forty feet, which, at the above rate, would make the age of the deposit at this point about 13,500 years. The alluvial deposit of the Nile is much thicker at some points than forty feet; but, on the other hand, the rate of increase for different places is probably variable.

The age of a delta is usually estimated by dividing the cubic contents of the delta by the annual mud-discharge. The cubic contents of the delta are estimated by multiplying the superficial area by the mean depth. The mean depth of the Mississippi Delta, as determined by borings, is taken by Mr. Lyell as 528 feet, the superficial area at 13,600 square miles, and the annual mud-discharge at 7,400,000,000 cubic feet. Upon these data he makes the probable age of the delta 33,500 years. To this he adds half as much for the age of the river-swamp, making in all 50,000 years.

FIG. 21.—Delta and Submarine Bank.

It is evident, however, that this estimate cannot be relied on as even approximately accurate. For there is no reason why the time of river-swamp deposit should be added to that of the delta, for they were both probably formed at the *same*

[1] *Philosophical Magazine*, vol. xvi., p. 225.

time—one by deposits higher up the river, the other by deposits at the mouth. Again, on the other hand, the estimate takes no account of the *submarine extension of the delta*, in area certainly, and in cubic contents probably, much greater than the subaërial delta. Figs. 20 and 21 are an ideal section and a map of a delta, in which *a* is the aërial and *b* the submarine portion. This would greatly increase the time.

It is evident, therefore, that although the problem is one of great interest, we are not yet in possession of data to make a reliable estimate. Every estimate, however, indicates a very great lapse of time.

But it must not be imagined, as all estimaters seem to do, that this time, be it greater or less than Mr. Lyell's estimate, belongs all to the present geological epoch. Prof. Hilgard has shown that the true alluvial deposit of the Mississippi is only *forty or fifty feet thick.* Beneath this the deposit belongs to the Quaternary or preceding geological epoch.

5.—*Estuaries.*

We have already seen that rivers which empty into tideless seas communicate with the sea by numerous branches traversing an alluvial flat, formed by the deposits of the river; while rivers emptying into tidal seas communicate by wide mouths or bays, formed by the erosive action of the flowing and ebbing tide. Such bays are called *estuaries.* We have fine examples of estuaries in the Amazon and La Plata Rivers, in the Delaware and Chesapeake Bays, in the friths of Scotland and the fiords of Norway: in fact, at the mouths of all the rivers emptying into the Atlantic on our own coast as well as on the European coast. The mouth of the Columbia River is a good example on the Pacific coast. The phenomena of a delta and an estuary are sometimes combined in the same river. This is the case to some extent in the Ganges.

Mode of Formation—Estuaries are evidently formed by the erosive action of the inflowing and outflowing tide. Their shape, narrow above and widening toward the sea, gives great force to the tidal current, which, entering below and concentrated in the ever-narrowing channel, rushes along with prodigious velocity and rises to an immense height. In the Bay of Fundy the tide rises seventy feet, and at Bristol, England, it rises forty feet, in Puget Sound twenty-five feet. Sometimes, from obstructions at the mouth of the river, the tide enters as one or more immense waves, rushing along like an advancing cataract. This is called an *eagre* or *bore.* The finest examples are perhaps in the Amazon and Tsien-tang Rivers. In the eagre of the Amazon "the tide passes up in the form of five or six waves following one another in rapid succession, and each twelve to fifteen feet high." In the Tsien-tang, a single wave plunges along at the rate of twenty-five miles an hour,[1] with perpen-

[1] *American Journal of Science and Arts*, 1855, vol. xx., p. 305.

dicular front, like an advancing cataract, four or five miles wide and thirty feet high. In the river Severn also we have a remarkable example of an eagre. According to the laws already developed (p. 19), the erosive and transporting power of such currents must be immense.

Deposits in Estuaries.—The larger portion of the materials thus eroded is carried out to sea by the retreating tide, and will be again spoken of under "Sea-deposits." A portion of these materials, however, is always deposited in the estuary in sheltered coves and bays (Fig. 22, *a* and *b*), and often, when the outflowing tide is obstructed by sand-spits and islands at the mouth, over every portion of the estuary. In addition to this, especially in rivers subject to great freshets, there are deposits of silt from the river. Thus many estuaries are occupied alternately, during the wet and dry seasons, by fresh and brackish or salt water, and the deposits in them are therefore alternately fresh-water and salt-water deposits, containing fresh-water and salt or brackish water shells. These alternations are highly characteristic of estuary-deposits in all geological periods; in fact, of all deposits at the mouths of rivers where river and ocean agencies meet.

6.—*Bars.*

Bars are invariably formed in accordance with the law already enunciated as that controlling all current-deposits, viz., if the velocity of a current bearing sediment be checked, the sediment is deposited.

There are two positions in which bars are formed: 1. At the mouths of rivers; and, 2. At the head of the estuaries. In the first position

FIG. 22.—An Estuary.

(Fig. 22, *d d*) the bar is formed by the contact of the river-current with the still water of the ocean. It is most marked in the case of estuaries. The outflowing tide scours out the estuary, carrying with it sediment partly brought down by the river, and partly the *débris* of land eroded by the inflowing tide. The larger portion of this is dropped as soon as the tidal current comes in contact with the open sea and is checked by it. They are usually irregularly crescentic in form. Such are the bars at the mouths of all harbors. In the second position they

are found just where the upward current of the inflowing tide meets the downward current of the river, and makes *still water.* At this point we have not only a bar, but usually also an extensive marsh caused by the daily overflow of the river. Through this marsh the river winds in a very devious course, as is common in all rivers whose banks are alluvial.

Thus, then, in rivers like the Mississippi, emptying into tideless seas and forming deltas, there is but one bar, viz., that at the mouth; while in rivers forming estuaries there are two bars, an *outer* and an *inner.* This inner bar may be many miles up the river. In the Hudson River the inner bar is 140 miles up the river, and only a few miles below Albany. This is really the head of tide-water in this river.[1]

Bars, being produced by natural and constantly-acting causes, *cannot usually be permanently removed*, though they may be sometimes greatly improved. If they are scraped away by dredging-machines, they are speedily reformed on the same spot. If we cause the river itself to remove them, as has sometimes been done by narrowing the channel and thus increasing the erosive power, we indeed remove the bar, but it is reformed farther down stream at a new point of equilibrium.

We have thus traced river agencies from their source to the sea. This brings us naturally to ocean agencies.

Section 2.—Ocean.

Waves and Tides.

Waves.—Waves produce no current, and therefore no geological effect in deep water. The erosive effect of this agent is almost entirely confined to the coast-line, but at this point is incessant and powerful. The average force of waves on the west coast of Scotland for the summer months is estimated by Stevenson at 611 pounds per square foot, and for the winter months at 2,086 pounds per square foot.[2] In violent storms the force is estimated at 6,000 pounds per square foot,[3] and fragments of rock of many hundred tons' weight are often hurled to a considerable distance on the land. These fragments hurled against the shore are the principal agent of wave-erosion. The rapidity of the erosion of a coast-line by the action of waves is determined partly by the softness and partly by the inclination of the strata. If the strata turn their faces to the waves, particularly if inclined at a small angle, the effect of the waves is comparatively slight (Fig. 23); but if the edges of the strata are exposed to the waves, the

[1] There is another important principle affecting the formation of bars in rivers emptying into seas, viz., the flocculation and consequent precipitation of clay sediments, by salt-water (Hilgard).

[2] Dana's "Manual," p. 654. [3] Herschel's "Physical Geography," p. 75.

erosion is much greater. For instance, if the strata be horizontal, as in Fig. 24, then the strata are undermined and form overhanging table-rocks, which from time to time fall into the sea; if the strata are vertical or highly inclined and their edges turned to the sea, then an exceedingly irregular coast-line is formed and the erosion is very rapid, as the force of the waves is concentrated upon the reëntering angles. Fig. 25 is a map view of a coast, in which from *a* to *b* the waves strike the edges, while from *a* to *c* they strike the faces of the same rocky strata. The difference in the form of the coast-line is seen at a glance.

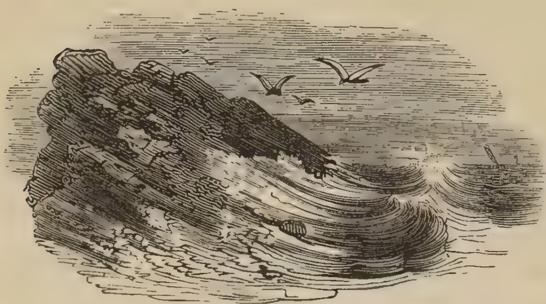


FIG. 23.

Waves cutting ever at the shore-line only, act like an *horizontal saw.* The receding shore-cliff, therefore, leaves behind it an ever-increasing subaqueous platform which marks the amount of recession. This is shown in the section (Fig. 26), in which *s* is the present shore-line, *l* the water-level, *a b* the platform, *s′* the original shore-line, and *s′ b c* the original slope of bottom. The recession of the shore-line and the formation of the shore platform have been accurately observed in Lake Michigan (Andrews). Level platforms terminated by cliffs, therefore, when found inland, sometimes indicate the position of old shore-lines.

FIG. 24.—Section of an Exposed Cliff.

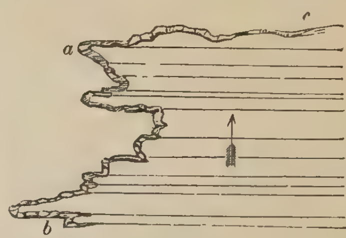


FIG. 25

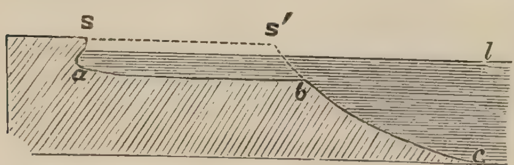


FIG 26.

Tides.—The tide is a wave of immense base, and three or four feet in height in the open ocean, produced by the attractive force of the moon

and sun on the waters of the ocean. The velocity of this wave is very great, since it travels around the earth in twenty-four hours. In the open ocean it produces very little current, only a slow transfer of the water back and forth, too slow to produce any geological effect;[1] but in shallow water, where the progress of the wave is impeded, it piles up in some cases forty to fifty feet in height, and gives rise to currents of great velocity and immense erosive power. By this means bays and harbors are formed, and straits and channels are scoured out and deepened. Tides also act an important part in assisting the action of waves upon the whole coast-line. The action of waves on exposed cliffs quickly forms accumulations of *débris* at their base, composed of sand, mud, shingle, or rocky fragments (Fig 24), which receive first and greatly diminish the shock of the waves upon the cliff. The incessant beating of the waves upon this *débris* reduces it to a finer and finer condition, and the retreating waves bear much of it seaward; so that, even without the assistance of any other agent, the protection is incomplete, and the erosion therefore progresses. But if strong tidal currents run along the coast, these effectually remove such *débris* and leave the cliff exposed to the direct action of the waves.

Examples of the Action of Waves and Tides.—The coasts of the United States show many examples of the erosive action of waves and tides. The form of the whole New England coast is largely determined by this cause. The softer parts are worn away into harbors by the waves and scoured out by the tides, while the harder parts reach out like rocky arms far into the sea. Sometimes only small rocky islands, stripped of every vestige of earth, mark the position of the former coast-line. Boston Harbor and the rocky points and islands in its vicinity are good examples. The process is still going on, and its progress may be marked from year to year.

On the Southern coast examples of a similar process are not wanting. At Cape May, for instance, the coast is wearing away at a rate of about nine feet per annum. The more exposed portions about Charleston Harbor, such as Sullivan's Island, are said to be wearing away even more rapidly. As a general fact, however, the low, sandy or muddy shores of the Southern coasts are receiving accessions more rapidly than they are wearing; while, on the contrary, the New England coast, as proved by its rocky character, is losing much more than it gains. The shores of Lake Superior (Fig. 27) furnish many beautiful examples of the action of waves, in this case, of course, unassisted by tides. The general form of the lake along its south shore is determined by the varying hardness of the rock; the two projecting promontories La Pointe (*a*) and Keweenaw Point (*c*) being composed of hard, igneous rocks, while the intervening bays *b* and *d* are softer sandstone.

[1] Herschel's "Physical Geography," p. 64.

On the south shore, about *e*, between La Pointe and Fond du Lac (*f*), the conditions of rapid erosion are beautifully seen. The shores are sandstone cliffs, with nearly horizontal strata. These have been eroded beneath by the waves, in some places for hundreds of feet, forming

FIG. 27.—Lake Superior.

immense overhanging table-rocks, supported by huge sandstone pillars of every conceivable shape. Among these huge pillars, and along these low arches and gloomy corridors, the waves dash with a sound like thunder. From time to time these overhanging table-rocks, with their load of earth and primeval forests, fall into the lake.

The coasts of Europe furnish examples on a more magnificent scale, and have been more carefully studied. The cliffs of Norfolk are carried away at a rate of three feet, and those of Yorkshire six feet, annually. The church of Reculver, on the coast of Kent, near the mouth of the Thames, stood, in the time of Henry VIII., one mile inland. Since that time the sea has steadily advanced until, in 1804, a portion of the churchyard fell in, and the church was abandoned as a place of worship. The church itself, ere this, would have been undermined and fallen in, had it not been protected by artificial means. There are many instances in the German Ocean of islands which have been entirely washed away during the historic period.

The tidal currents through the British and Irish Channels, along the western coasts of Ireland and Scotland, among the Orkneys and Hebrides, and especially along the coast of Norway, are very powerful. Along this latter coast it forms the celebrated Maelstrom. The erosive effects of the sea are, therefore, very conspicuous. On the south and east coasts of England the erosion is now progressing rapidly. On the west coasts of Ireland and Scotland the waste is not now so great, because the softer material is all removed, but the configuration of the coast shows the waste which it has suffered. A glance at a good map

of Ireland shows a deeply-indented western coast, composed entirely of alternating rocky promontories and deep bays. On the western coast of Scotland, and especially on the Orkney, Shetland, and Hebrides Islands, the wasting effect of the sea has been still greater. Not only

FIG. 28.

have we here the same character of coast as already described (as seen in the friths of Scotland), but many small islands have been eroded, until only a nucleus of the hardest rock is left; and even these have been worn until they seem but the ghastly skeletons of once-fertile islands. Figs. 28 and 29 will give some idea of the appearance of these spectral islands.

The coast of Norway consists entirely of deep fiords alternating

FIG. 29.

with jutting headlands of hardest rock several thousand feet high. Along this intricately-dissected coast there runs a chain of high, rocky islands, which in an accurate map is scarcely distinguishable from the coast itself, being separated only by narrow, deep fiords. Toward the

northern part of the coast the crest of the Scandinavian chain seems to run directly along the jutting promontories of the coast-line, for these headlands are the most elevated part of the country; in fact, in some parts, it would seem that the original crest was at one time still farther west, along the line of coast-islands. If so, then the sea has not only carried away the whole western slope, but has broken through the main axis, leaving only these isolated rocky islands as monuments of its former position, and is even now carrying its ravages far inland on the eastern slope. In the case of Norway, however, and probably in case of nearly all bold, rocky coasts, the intricacy of the coast-line is not due wholly or even principally to the action of waves and tides, but also to other causes to which we shall refer hereafter.

Transporting Power.—The transporting power of waves is immensely great, often taking up and hurling on shore masses of rock hundreds of tons in weight; but, being entirely confined to the coast-line, the *distance* to which they carry is necessarily very limited. There are some instances, however, of materials carried to great distances by the incessant action of waves. Thus, according to Prof. Bache, coast-sand is carried slowly farther and farther south by the action of waves, and siliceous sand is found at Cape Sable on the extreme southern point of Florida, although the whole Florida coast as far as St. Augustine is composed of coral limestone alone. He accounts for this by supposing that the trend of the United States coast is such that waves coming from the east strike the coast obliquely and fall off toward the south, carrying each time a little sand with them. A similar phenomenon has been observed on Lake Michigan: the sands are carried steadily toward the south end, where they accumulate.

Deposits.—The invariable effect of waves, chafing back and forth upon coast *débris*, is to wear off their angles and thus to form rounded fragments and granules. Thus pebbles, shingle, and round-grained sand, though produced by all currents, are especially characteristic of wave-action. *Ripple-marks* are also characteristic of current-action in shallow water. They are, therefore, always formed on shore by the action of waves and tides. By means of these characteristics of shore deposit, many coast-lines of previous geological epochs have been determined.

We have seen that waves usually *destroy* land. In many cases, however, they also *make* land. This is the case whenever other agencies, such as river or tidal currents, drop sediment in shallow water, and therefore within reach of wave-action. We shall again speak of these under the head of Land formed by the Ocean Agencies.

Oceanic Currents.

The ocean, like the atmosphere, is in constant motion, not only on its surface, but throughout its whole mass. The general direction of the currents in the two cases is also similar, but there are disturbing and complicating causes peculiar to each, which interfere with the regularity and simplicity of the phenomena. If the currents of the atmosphere are more variable on account of the greater levity of the fluid, oceanic currents have also their peculiar disturbing causes in the existence of impassable barriers in the form of continents. In both atmosphere and sea, currents may also be deflected by *submarine banks*, for mountain-chains are the banks of the aërial ocean.

Theory of Oceanic Currents.—By some distinguished physicists, oceanic currents have been attributed entirely to the action of the *trade-winds.*[1] There can be no doubt that this is a *real cause;* yet it seems probable, nay, almost certain, that the great and controlling cause of currents of the ocean, as of the air, is difference of temperature between the equatorial and polar regions.[2] We will, therefore, discuss the subject from this point of view, although the effect would be much the same, whatever be our view of the theory. For the sake of clearness, we will take first the simplest case, and then introduce disturbing influences and show their effects.

Suppose, first, the earth covered with a *universal ocean*, continually heated at the equator, and cooling at the poles: the difference of density of the equatorial and polar seas would cause exchange or circulation between these regions by means of *north and south currents in all longitudes*, the equatorial currents being superficial because warm, and the polar currents deep-seated because cold. It is obviously impossible, however, that the principal exchange should be with the *pole* itself, since this is but a point, but with the northern *regions.* Observation shows that it is between the equator and the *polar circle.* In the case we are now considering, the exchange, being in all longitudes, would be scarcely, if at all, perceptible.

Suppose, second, the earth be set a rotating: then the currents passing from either polar to the equatorial region would be deflected more and more to the westward until, uniting at the equator, they would there form a directly westward equatorial current running around the earth. This westward-moving water would be constantly turning northward and southward in all longitudes as a superficial current, and finally eastward about the polar circle, to join again the deep-seated polar current going to the equator; thus forming a series of regular ellipses lying over each other in strata, dipping eastward and outcropping

[1] Herschel, "Physical Geography," p. 13; and Croll, "Climate and Time."

[2] Guyot, "Earth and Man," p. 189.

westward—as represented in Fig. 30. As the north and south currents $a\ a'$ and $b\ b'$ would take place in all longitudes, they would be scarcely, if at all, perceptible; but the east currents $d\ d'$, and the westward equatorial current $c\ c$, where all these unite, would be decided.

In the third place, introduce *continents* passing across the equator from north to south, forming impassable barriers to the east and west currents $c\ c$ and $d\ d$. Then many of the lines of current $a\ a\ a$ would be crowded against the western shore of the ocean, and of the lines $b\ b\ b$ against the eastern shore, forming in each case by concentration very decided currents, while in mid-ocean these currents would be still imperceptible. Thus the *perceptible* currents of an ocean situated between continents would be represented by the figure (Fig. 31) taken from Dana.

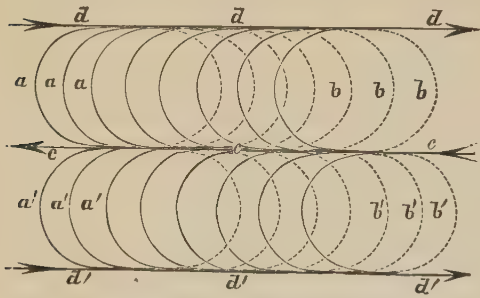


FIG. 30.—The strong lines $a\ a\ a$ show superficial, and the dotted lines $b\ b\ b$ deep-seated currents.

Besides the main currents above mentioned there would be minor exchanges with the pole itself.[1] A portion of the eastward current d and d' would turn north and southward, $e\ e'$, and circling around would return toward the equator as a deep-seated current under a, hugging the shore on account of the westward tendency of all currents moving toward the equator.

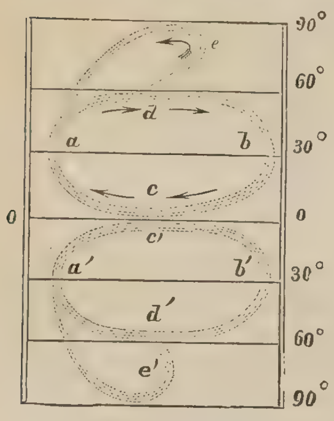


FIG. 31.—Ideal Diagram, showing General Course of Oceanic Currents.

The effect of the trade-winds would be to conspire with the cause already discussed in the formation of the equatorial current $c\ c'$, and by the reflection of this from continents, the other currents spoken of.

Application.—We will now apply these principles in the explanation of the currents of the Atlantic Ocean, for these are best known.

Currents coming from the north and south on the African coast, and corresponding to $b\ b'$ in the above diagram, unite to form an equatorial current, $c\ c'$, which stretches across the Atlantic until, striking (Fig. 32) against the coast of South America, it turns north and south, $a\ a'$. The

[1] Dana's "Manual," p. 38.

southern branch has not been accurately traced. It probably turns gradually eastward, d', and forming a grand circle in the southern Atlantic joins again the South African current b'. The northern branch, a, runs along the coast of South America, through the Caribbean Sea and into the Gulf of Mexico, from which emerging it runs with great velocity through the narrow straits of Florida and thence under the name of the Gulf Stream along the coast of North America, turning

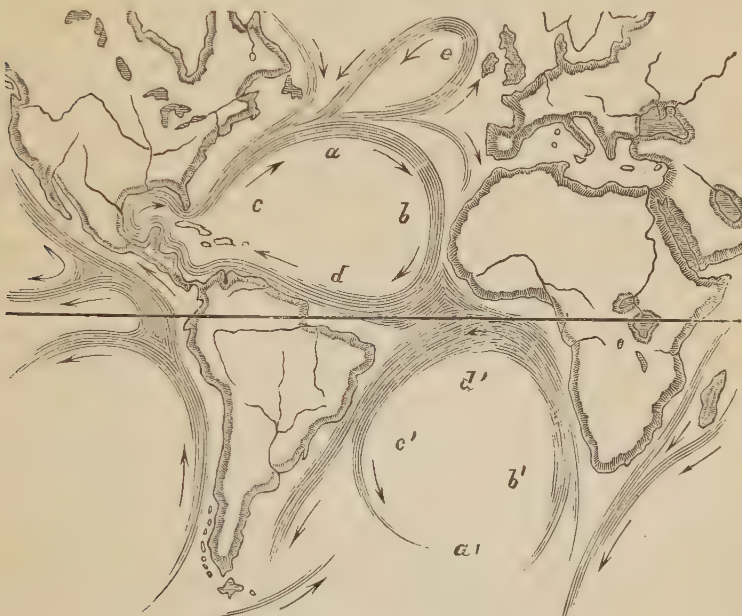


FIG. 32.—General Course of Currents of the Atlantic.

more and more eastward in obedience to the law already mentioned, until it becomes an eastward current, d, about 50° to 60° latitude; and then stretches across to the coast of Europe, and turns again southward to join the equatorial current. A portion of it, however, in its eastward course turns northward, e, and returns as a cold polar current hugging the shore of North America as a *cold wall* to the Gulf Stream, and thus passes south.

Geological Agency of Oceanic Currents.—The velocity of oceanic currents is generally small, although, in the case of the Gulf Stream, at the Florida Straits, it reaches almost the velocity of a torrent, viz., three and a half to five miles per hour. The volume of water carried by them is almost inconceivably great; it is estimated that the Gulf Stream alone carries many times more water than all the rivers of the globe. According to Croll, it is equal to a current fifty miles wide and

one thousand feet deep, running at a rate of four miles per hour. The geological agency of these powerful currents in modifying the bottom of the sea by erosion *may* be, and by sedimentary deposit *must* be, very important, though as yet comparatively little known.

One of the chief functions of oceanic currents is the transportation and distribution over the open-sea bottom of sediments brought down by the rivers. By far the larger part of the *débris* of the land is certainly dropped near the shore, and marginal sea-bottoms are everywhere the great theatres of sedimentation; but, without the agency of marine currents, none would reach open sea, *all* would be dropped near shore. By the agency of these, however, the *finer* portions are carried and widely distributed over certain portions of deep-sea bottoms. We have undoubted evidence of this in some cases. Thus the sediments brought down by the Amazon are swept seaward by a strong tide, and then taken by the oceanic current which sweeps along that coast, and carried 300 miles and deposited much of it on the coast of Guiana. According to Humboldt, the same stream carries sediment from the Caribbean into the Gulf of Mexico.[1] There is little doubt, too, that much of the sediments brought into the Gulf of Mexico by the Gulf rivers is swept along by the Gulf Stream, and a part of it deposited on Florida Point and the Bahama Banks. The surface transparency of the Gulf Stream is no objection to this view, as a little reflection will show. Ocean-currents differ from rivers, in the fact that the former run in perfectly smooth *beds of still water*. There are, therefore, no subordinate currents from side to side, or up and down, whereby in river-currents the water is thoroughly mixed up, and the finer sediments prevented from settling. In ocean-currents the conditions are as favorable for subsidence as in still water. It is evident, therefore, that sediments carried by ocean-currents must in a little time sink out of sight, although from the great depth of these currents they may still be carried to considerable distances. Deep-sea deposits have until recently received little attention, although they are acknowledged to be of the greatest geological importance.

Submarine Banks.—These are always accumulations of material dropped by currents. They are formed under conditions similar to those which determine the formation of bars; i. e., either by the meeting of opposing sediment-laden currents or else by such a current coming in contact with still water. In fact, the outer bar is a true submarine bank. The currents may be either tidal or oceanic or river. Admirable examples of both these modes of formation are found in the German Ocean. The tidal wave from the Atlantic strikes the British Isles, passes round in both directions, and enters this ocean from the north around the north point of Scotland, and from the south through the

[1] Lyell's "Principles of Geology."

British Channel and Straits of Dover (Fig. 33). These two currents coming from opposite directions meet and make still water, and therefore deposit their sediment and form banks. Again, the tidal current is concentrated in the British Channel, and runs with great velocity, scouring out this channel, and in addition gathering abundant sediment from the rivers emptying into the channel. Thus loaded with sedi-

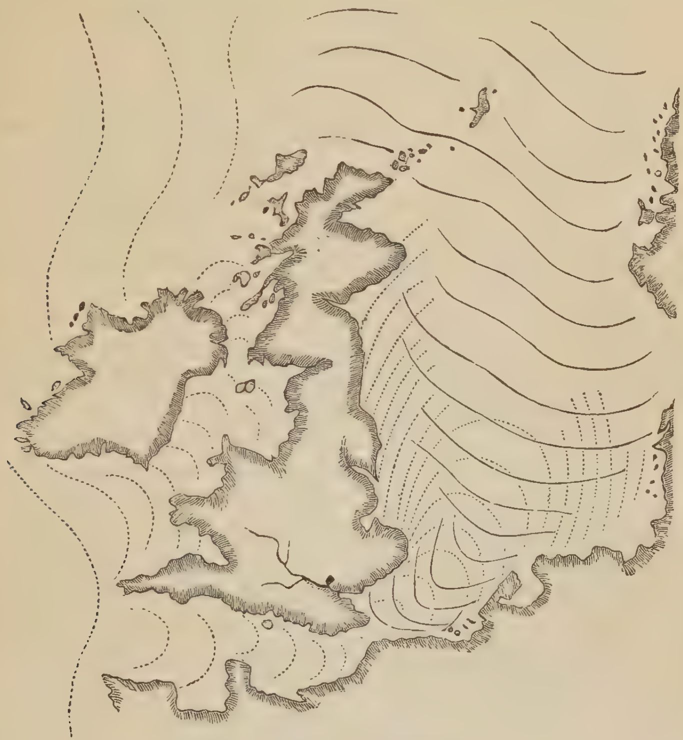


Fig. 33.—Tides of the German Ocean.

ment it rushes through the narrow Straits of Dover, and, coming in contact with the still water of the German Sea, forms eddies on either side, and deposits its sediments. Besides the banks thus formed, there are, of course, bars formed at the mouths of the rivers emptying into this shallow sea. By a combination of all these causes, we explain the numerous banks which render the navigation of this sea so dangerous.

But great banks far away from shore are usually formed by oceanic currents. Thus the Banks of Newfoundland are evidently formed by the meeting of the polar current (*e*, Fig. 32), bearing icebergs loaded with earth, and the warm current of the Gulf Stream, perhaps also bearing its share of fine sediment. Again, the Gulf Stream, rushing at

high velocity (four miles per hour) through the narrow Straits of Florida, coming in contact with the still water of the Atlantic beyond and forming eddies on each side, and depositing sediment, has certainly contributed to form, if it has not wholly formed, the Bahama Banks on one side, and the bank on which the Florida reefs are built on the other. It is probable that many other peculiarities of the Atlantic bottom in the course of the Gulf Stream may be similarly accounted for.[1]

Land formed by Ocean Agencies.—Upon submarine banks, however these may be produced, are gradually formed islands. These islands are always formed by the immediate agency of waves. As soon as the submarine bank rises so near the surface that the waves touch bottom and form breakers, these commence to throw up the sand or mud until an island is formed, which continues to grow by the same agency, until it becomes inhabited by plants and animals, and finally by man. The height of such islands above the sea will depend upon the height of the tides and the force of the waves. They are seldom more than fifteen feet above high water. Thus, we find that extensive banks are always dotted over with islands. In this manner are formed the low islands so common about the mouths of harbors and estuaries, also the narrow *sand-spits* all along our Southern coast, separating the harbors and sounds from the ocean. Fig. 34, which is a map of the North Carolina coast, will give a good idea of these sand-spits. In the course of time such sounds, being protected in some measure by the sand-spits from the scouring action of the tides, are gradually filled up with sediments brought down by the rivers, leaving only narrow passages for the flow of the tide. In this manner were formed the *sea-islands* all along our Southern coast, separated from the mainland only by narrow tidal inlets. These tidal inlets may become filled up, and the whole coast-line transferred farther seaward.

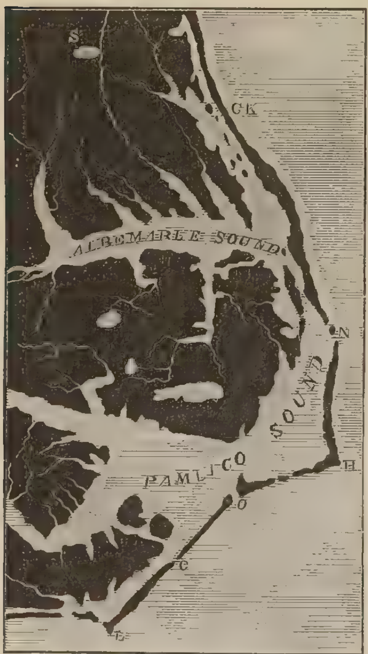


Fig. 34.—Coast of North Carolina.

A large portion of the coasts of the world is thus bordered by wave-

[1] *See* the author's views on this subject, *American Journal of Science*, vol. xxiii., p. 46, 1857.

formed islands. We have already seen, however, that on some coasts, e. g., Norway, Scotland, etc., islands are formed by the *destructive* action of waves. *Bordering islands*, so common along all coasts, are therefore of two classes, and formed by two opposite effects of waves—the one land-destroying, the other land-forming. The islands of one class are high and rocky, of the other low and sandy or muddy; the former are the scattered remains of an old coast-line, the latter the commencing points of a new coast-line.

Section 3.—Ice.

The agency of ice will be considered under the heads of Glaciers and Icebergs; the effects of frost in disintegrating rocks having been already treated of under Atmospheric Agencies. It is only comparatively recently that the great importance of ice as a geological agent has been recognized. To Agassiz is due the credit of having first fully recognized this importance.

Glaciers.

Definition.—In many parts of the earth, where the mountains reach into the region of perpetual snow, and other favoring conditions are present, we find that the mountain-valleys are occupied by masses of compact ice, connected with the snow-cap above, but extending far below the snow-line into the region of cultivated fields, and moving slowly but constantly down the slope of the valley. Such valley-prolongations of the perpetual snow-caps are called *glaciers.* The existence of glaciers, and their motion, is necessitated by the great *law of circulation*, so universal in Nature. For in those countries where glaciers exist, the waste of perpetual snow by evaporation is small in comparison with the supply by the fall of snow. There would be no limit, therefore, to the accumulation of snow on mountain-tops, if it did not run off, down the slope, by these ice-streams, and thus return into the general circulation of meteoric waters. Glaciers extend not only far below the snow-line, but even far below the mean line of 32°. In the Alps the snow-line is about 9,000[1] feet above the sea-level, while some of the glaciers extend down to within 3,400 feet of the same level, i. e., more than 5,000 feet below the snow-line.

Necessary Conditions.—The conditions necessary to the formation of glaciers are: 1. The mountain must rise into the region of perpetual snow, for the snow-cap is the fountain of glaciers. 2. There must be considerable changes of temperature, and therefore alternate thawings and freezings. This condition seems necessary to the gradual compacting of snow into glacier-ice. The want of this condition is apparently the cause of the non-existence, or small development, of glaciers in

[1] Dana's "Manual of Geology."

tropical regions. 3. A moist atmosphere is favorable to their production, for the moister the climate the greater is the snow-fall, and the smaller is the waste by evaporation, and therefore the greater the excess which must run off by glaciers. This is an additional reason why glaciers are not formed under the equator; for the great capacity for moisture of the air in this zone increases the waste while it decreases the fall of snow. This is also the reason of the scanty formation of glaciers in the Sierra Mountains, and their abundance and magnitude in the Alps.

Ramifications of Glaciers.—We have said glaciers are valley-prolongations of the ice-cap. Now, mountain-valleys are of two kinds, viz.: 1. The deeper and larger *longitudinal valleys*, between parallel ranges; and, 2. The *transverse* or *radiating valleys*, transverse in case of ridges, and radiating in case of peaks. The longitudinal valleys may be formed either by erosion or by igneous agencies folding the crust of the earth; but the transverse or *radiating valleys are always formed by erosion.* It is these valleys of erosion which are occupied by glaciers. In countries where there are no glaciers they are occupied, of course, by streams. We have already shown (p. 9) how these valleys commence near the top of the mountain as furrows, which, uniting, form gullies, and these, in their turn, forming ravines and gorges, thus becoming less and less numerous, but larger as we approach the base of the mountain. In the same manner, therefore, as streams ramify, so also do glaciers. The only difference is the degree of ramification. Streams ramify almost infinitely, while glaciers seldom have more than three or four tributaries. Fig. 35 is a map of the Mont Blanc glacier-region. By inspection of this map it will be seen that the *Mer de Glace*, *m*, receives four tributaries, marked *t*, *l*, *g*, etc. On page 51 is an enlarged view of the same glacier, with its tributaries.

Motion of Glaciers.—Again, we have said in our definition that glaciers are in constant motion. By the law of circulation, constant downward motion is as necessary to the idea of a glacier as it is to that of a river, since both the glacier and the river carry away the excess of supply over evaporation. But a glacier, though in constant motion, never passes beyond a certain point, where the slow downward motion is exactly balanced by the melting of the ice by sun and air. This point is called the *lower limit* of the glacier. As long as conditions remain unchanged, the lower end of the glacier remains exactly at the same point, although the substance of the glacier moves always downward. But if external conditions change, the point of the glacier may move upward or downward. Thus, during a succession of cool, damp years, the melting being less rapid, the point of the glacier moves slowly down, sometimes invading cultivated fields and overturning huts, until it finds a new point of equilibrium. During a succession of warm and dry years,

Fig. 35.—Mont Blanc Glacier Region: *m*, Mer de Glace; *g*, Du Géant; *l*, Lechaud; *t*, Talafré; *B*, Bionassay; *b*, Bosson.

on the contrary, the melting being more rapid, the point retreats, to find a new point of equilibrium higher up the mountain. But, whether the point be stationary, or advance or recede, the substance of the glacier is ever moving steadily onward. It may be compared to those rivers, in dry, sandy countries, which run ever toward the sea, but never reach beyond a certain point, being absorbed by the sand.

Graphic Illustration.—These facts may be conveniently represented as follows: Let *a d* (Fig. 36) equal the length of the mountain-slope, and the line *a b* (= *c d*) the velocity of the glacier-motion taken as uniform. This velocity varies with the slope, as will be seen hereafter, but is little affected by the elevation. It may be taken, therefore, as the same in every part of the slope, and therefore correctly represented by equal lines, i. e., by the ordinates of the parallelogram *a b c d*. The melting power of the sun and air, on the contrary, regularly increases from the top, where it is almost nothing, to the bottom of the mountain. We will, therefore, represent it by the increasing ordinates of the triangle *a e d*. At *x*, therefore, where the ordinates of the triangle and of the parallelogram are equal to each other, will be the lower limit of the glacier. During a succession of cool years the rate of melting will be represented by the ordinates of the smaller triangle *a g d*, and the point of the glacier will advance to *z*. During a succession of warm, dry years, the rate of melting will be represented by the larger triangle *a f d*, and the point of the glacier will recede to *y*.

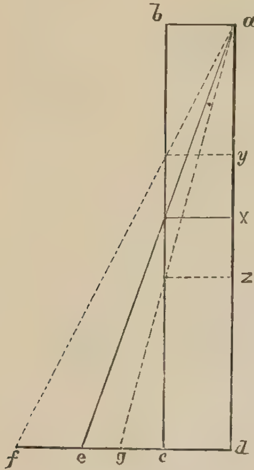


Fig. 36.

Line of the Lower Limit of Glaciers.—We have said, again, that the glacier reaches below the snow-line. There are three lines, or rather *spheroidal surfaces*, running above the surface of the earth, which are apt to be confounded with one another, and must, therefore, be now defined. These are the *line of perpetual snow*, the *mean line of* 32°, and the *line of the lower limit of glaciers*. The line of perpetual snow, at the equator, is about 16,000 to 17,000 feet above the sea-level. As we approach the poles it gradually approaches the sea-level, until it touches at or near the poles, forming thus a spheroid more oblate than the earth itself (Fig. 37). Next follows the mean line of 32°. This commences at the equator, *E*, coincident with the snow-line (it may be even above it—Dana), but diverges as we pass toward the pole, and finally touches the sea-level at about 66° north and south latitude, at *b b*. Below this, again, is the line of lower limit of glaciers, which, commencing again nearly coincident with the two preceding, at

the equator, approaches and touches the sea-level at about 50° latitude, or, under favorable circumstances, at even lower latitudes. The difference between these lines is often several thousand feet. In the Alps, the line of 32° is 2,000 feet, and the line of lower limit of glaciers 5,000 feet, below the snow-line. In some parts of the arctic region, the line of 32° is 3,500 feet below the snow-line, and in Norway the lower limit of glaciers is 4,000 feet below the line of 32° (Dana). For the sake of simplicity we have represented the surfaces, of which these lines are the sections, as regular spheroids; but, in fact, they are very irregular, being much influenced by climate. Their intersection with the sea-level will, therefore, not be along lines of latitude, but will be irregular, like isotherms. As the line *a c* marks the lower limit of glaciers in different latitudes, it is evident that at *c* glaciers will touch the sea, and beyond this point will run far into the sea. It is in this manner, as we will see hereafter, that icebergs are formed. In Chili, glaciers touch the sea-level at 46° 40′ south latitude.[1]

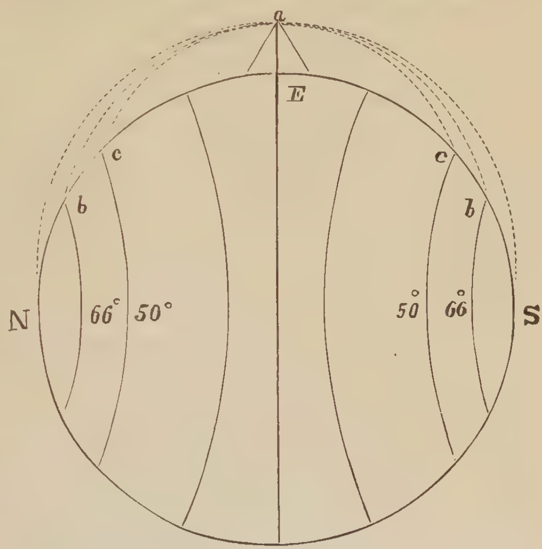


FIG. 37.—General Relation of Limit of Glaciers to Snow-Line.

General Description.—In glacial regions a mountain-valley is occupied in its highest part by perpetual snow; below this, farther down the valley, by *névé*—a granular snow, intermediate between snow and ice; still farther down, by true glacier-ice; and, finally, by a *river* (Fig. 41). This river is formed partly by the melting of the whole surface of the glacier, both above and below, and partly by the natural drainage of the valley. The glacier, however, is the principal source. From the point of every glacier, therefore, runs a river.

The *size* of glaciers varies very much. Alpine glaciers are some of them fifteen miles long, and vary from half a mile to three miles in breadth, and from one hundred to six hundred feet in thickness. In the region about Mont Blanc and Finsteraarhorn alone there are about four hundred glaciers. In the temperate regions of North America, gla-

[1] D'Archiac, "Histoire de Géologie."

ciers are found only on the Pacific coast, in the Sierra and Cascade Ranges. On Mount Shasta, and especially on Mount Rainier, glaciers equal to those of the Alps have been recently found. In the Himalaya Mountains they are developed upon a much more gigantic scale; but it is only in arctic regions that we can form any just conception of their immense importance as geological agents. In Spitzbergen, a glacier was seen eleven miles wide and four hundred feet thick at the point.[1] Of course, this thickness only represents the part above water. By far the larger part, or six-sevenths, is below water-level. In Greenland the great Humboldt Glacier enters the sea with a point forty-five miles wide and three hundred feet thick (Kane). But even these examples give an incomplete idea of the whole truth. Greenland is apparently entirely covered with an immense *sheet of ice*, several thousand feet thick, which moves slowly seaward, and enters the ocean through immense fiords.[2] Judging from the immense barrier of icebergs found by Captain Wilkes (United States Exploring Expedition) on its coast, the antarctic continent is probably even more thickly covered with ice than Greenland.

We are apt to suppose that the surface of a glacier must be smooth. This is, however, very far from being true. On the contrary, the extreme *roughness* of the ice-surface renders the ascent along the glacier extremely difficult. This inequality of surface is due partly to unequal melting, and partly to *crevasses*, or fissures. The unequal melting is produced as follows: A stone, lying on the surface of a glacier, protects the surface beneath from the rays of the sun. Meanwhile the surrounding ice is melted, until finally the slab of stone stands on a column of ice often several feet in height (Fig. 38). A slab seen by Forbes measured 23 feet long, 17 feet wide, and 3½ feet thick, and rested on a column 13 feet high. In such cases the stone finally falls off, leaving a sharp pinnacle, and another column commences to form under the stone. In this manner are formed what are called *needles*. When we consider that there are immense numbers of stones on the glacier-surface, we can easily see that these needles will multiply indefinitely. If, on the other hand, a *thin* stratum of earth stains the surface of the glacier in spots, these spots will melt *faster* than the surrounding ice, because more absorbent of heat, and thus form deep holes.[3]


FIG. 38.—Mode of Formation of Ice-Pillars.

Again, fissures or crevasses, often of great size, ten to twenty feet wide, one hundred feet deep, and sometimes running entirely across the glacier, are very abundant. As the surface of the glacier is often covered with snow, and the fissures thus concealed, they form the most

[1] Dana's "Manual." [2] Dr. Rink, "Archives des Sciences," vol. xxvii., p. 155.
[3] See APPENDIX.

dangerous feature connected with Alpine travel. The law which governs their formation will be discussed hereafter; suffice it to say that the great transverse fissures are formed by the glacier passing over an angle formed by a sudden change in the slope of the bed. Streams, produced by the melting of ice, running on the surface of the glacier, plunge into these fissures with a thundering noise, and hollow out immense wells, called *moulins*, and magnificent *ice-caves.* Although the

FIG. 39.—Inequalities of the Surface of a Glacier (after Agassiz).

glacier moves, the great crevasses and the wells with their falls remain *stationary*, precisely as the position of a rapid or breaker remains stationary, although the river runs onward; and for the same reason, viz., that it is reformed always on the same spot.

From all these causes the surface of a glacier is often studded over with conical masses and projecting points of every conceivable shape. This is well shown in the accompanying figure (Fig. 39).

Earth and Stones, etc.—The surface of a glacier is, moreover, largely covered with earth and stones gathered in its course from the crumbling cliffs on either side. These are often so abundant as almost to cover the surface. More usually, however, they are distributed in two or more rows, called *moraines.* Fig. 40 is a view of a glacier, with its moraines and lateral crevasses.

Such is a general description of the appearance of a glacier. There are, however, several points which, by their importance and interest, require special notice. These are: 1. *Moraines;* 2. *Glaciers as a geological agent;* 3. *Glacier-motion;* and, 4. *Glacier-structure.*

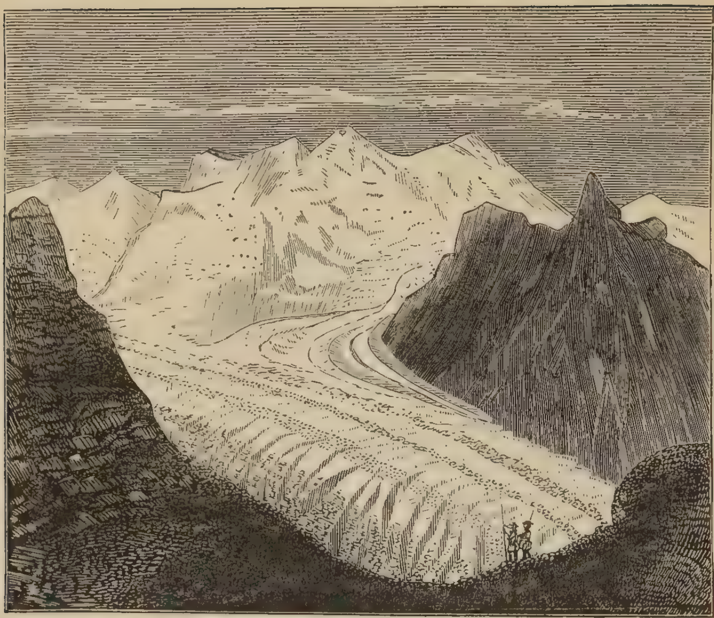


FIG. 40.—Zermatt Glacier (Agassiz).

Moraines.

There are three kinds of moraines described by writers, viz., *lateral* moraines, *medial* moraines, and *terminal* moraines. *Lateral moraines* are continuous lines of earth and stones, arranged on either margin of the glacier, and evidently formed from the ruins of the crumbling cliffs of the inclosing valley. This *débris* does not fall from every part of the valley-sides, but generally only from certain bold, projecting cliffs. It is converted into a continuous line by the motion of the glacier, just as light materials thrown constantly into a river at one point would appear as a continuous line on the stream.

Medial moraines are similar lines of *débris*, occupying the central portions of the glacier. Sometimes there is but one; sometimes two, or more; sometimes the whole surface of the glacier is almost covered with them. The true explanation was first pointed out by Agassiz. They are formed by the coalescence of the *interior* lateral moraines of *tributary* glaciers, carried down the main trunk by the motion of the ice-current. The accompanying map (Fig. 41) of the Mer de Glace and its tributaries shows clearly the manner in which these moraines are formed. Both lateral and medial moraines are generally situated on a ridge of ice, sometimes fifty to eighty feet high, evidently formed by the protection of the ice, in this part, from the melting-power of the

sun. The fragments of rock brought down by glaciers are often of enormous size. One described by Forbes contained 244,000 cubic feet.

Everything which falls upon the surface of the glacier is slowly and silently carried downward by this ice-stream, and finally dropped at its point. Much finely-triturated matter is also pushed along beneath the glacier, and finds its way to the same point. In the course of time an immense accumulation is formed, of somewhat crescentic shape, as seen in Fig. 41.

FIG. 41.—Mer de Glace.

This accumulation is called the *terminal moraine.* It is the *delta* of this ice-river. The existence of moraines is a constant witness of the motion of the glaciers.

Glaciers as a Geological Agent.

Glaciers, like rivers, *erode* the surface over which they move, *carry* the materials gathered in their course often to great distances, and finally *deposit* them. In all these respects, however, the effects of their action are perfectly characteristic.

Erosion.—When we consider the weight of a glaciers and their unyielding nature as compared with water, it is easy to see that their erosive power must be very great. This is increased immensely by fragments of stone of every conceivable size carried along between the glacier and its bed. These partly fall in at the sides and become jammed between the glacier and the confining rocks, partly fall into crevasses and work their way to the bed, and partly are torn from the rocky bed itself. The effects of glacier erosion differ entirely from those of water: 1. Water, by virtue of its perfect fluidity, wears away the softer spots of rock and leaves the harder standing in relief; while a glacier, like an unyielding rubber, grinds both hard and soft to one level. This, however, is not so absolutely true of glaciers as might be supposed. Glaciers, for reasons to be discussed hereafter, conform to large and gentle inequalities of their beds, though not to small ones,

acting thus like a very *stiffly viscous* body. Thus their beds are worn into very remarkable and characteristic smooth and rounded depressions and elevations called *roches moutonnées* (Fig. 42). Sometimes *large and deep hollows* are swept out by a glacier at some point where the

Fig. 42.—Roches Moutonnées of an Ancient Glacier, Colorado (after Hayden).

rock is softer or where the slope of the bed changes suddenly from a greater to a less angle. If the glacier should subsequently retire, water accumulates in these excavations and forms lakelets. Such lakelets are common in old glacial beds.

2. The *lines* produced by water-erosion, if detectible at all, are always more or less irregular and meandering; while those produced by glaciers are *straight* and *parallel* (Fig. 43).

Thus, smooth, gently-billowy surfaces, marked with straight parallel scratches, are very characteristic of glacial action. We will call such surfaces *glaciated*, and the process *glaciation.*

Transportation.—The transporting power of glaciers follows no law similar to that pointed out under rivers—in fact, it has no relation at all to velocity. The reason is, that the stone rests on the surface as a *floating body.* There is, therefore, no limit to the transporting power. Bowlders of 250,000 cubic feet are carried with the same ease and the same velocity as the finest dust.

Deposit—Balanced Stones.—A water-current carrying stones bruises and rounds their corners, and deposits them always in the most *secure* positions; but glaciers often deposit huge *angular* fragments of rock

in the most *insecure* positions—so nicely balanced, sometimes, that a touch of the hand will dislodge them. The reason is, they are set down by the gradually melting ice with inconceivable gentleness. Thus balanced stones, rocking-stones, etc., are common in glacial regions. In using these as a sign of glacial action, however, we must recollect

FIG. 43.—Glacial Scorings (after Agassiz).

that a bowlder dropped by any agent, or even a bowlder of disintegration (p. 6), may in time become a rocking-stone, by slow but irregular disintegration changing the position of the centre of gravity. But *angular erratics* in insecure positions are very characteristic of glacial action.

Material of the Terminal Moraine.—The material of the terminal moraine is very characteristic: 1. It consists of fragments of every conceivable size, from huge bowlders down to fine earth, mixed together into an heterogeneous mass entirely different from the neatly-sorted deposits from water. It is, therefore, entirely *unsorted and unstratified*, and without organic remains. 2. The mass consists of two parts, viz., that which was carried on the top of the glacier, and that which was forced out beneath (*moraine profonde*). The first consists of loose material containing angular, unworn fragments; the other of fine compact material containing fragments worn and polished, and scratched with straight parallel scratches, but in both cases entirely different from *water-worn* pebbles. In all respects, therefore, the action of glaciers is characteristic and cannot be confounded with that of water.

Evidences of Former Extension of Glaciers.—It is by evidence of this kind that the former great extension of glaciers in regions where they now exist, and the former existence of glaciers in regions where they no longer exist, have been proved. We have already stated that during a succession of cool, damp seasons, a glacier may extend far

beyond its previous limits. Similar changes take place also in the depth of a glacier. In a word, glaciers are subject to floods like rivers; only these floods, instead of being annual, are *secular*. Now, as rivers after floods leave floating material stranded on the banks, showing the height of the flood-water, so, in the decrease of a glacier, lines of bowlders are left stranded, often delicately balanced, on ledges high up the sides of the valley. These lines of bowlders mark the former height of the glacier. Some of these lines have been found in the Alps 2,000 feet above the present level. Fig. 44 is a cross-section of a glacial valley. The dotted lines show the former level. In the same valleys we find old terminal moraines (Fig. 45, a') miles beyond the present limit of the glacier. The characteristic planing, polishing, and parallel scoring, have been found equally far above the present level and beyond the present limit of Alpine glaciers.

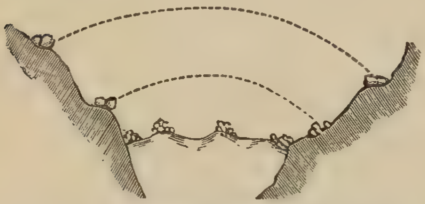


FIG. 44.—Section across Glacial Valley, showing old Lateral Moraines.

Glacial Lakes.—When a glacier retreats, the water of the river which flows from its point may accumulate in great *rock-basins* scooped out by the glacier, or else behind the old terminal moraines. In these two ways lakes are often formed.

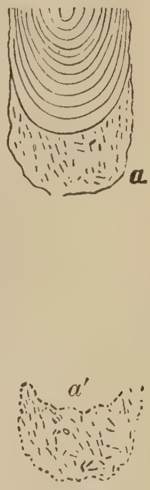


FIG. 45.—Old Terminal Moraines.

Motion of Glaciers and its Laws.

Evidences of Motion.—That glaciers move slowly down their valleys was long known to Alpine hunters. Rude experiments of the first scientific explorers, confirmed this popular notion. Hugi in 1827 built a hut upon the Aar glacier. This hut was visited from year to year by scientific explorers and its change of position measured. In 1841 Agassiz found that it had moved in all 1,428 metres in fourteen years, or about 100 metres (330 feet) per annum. Numerous other observations from year to year by Agassiz and others, on the position of conspicuous bowlders lying on the surface of glaciers, confirmed these results and placed the fact of glacier-motion beyond doubt. But the most important observations determining both the *rate* and the *laws* of glacier-motion were made in 1842 by Prof. Agassiz on the Aar glacier, and Prof. Forbes on the *Mer de Glace*. By these experiments, carefully made by driving stakes into the glacier, in a straight row from one side to the other, and observing the change in the relative position of the stakes, it was deter-

mined that the centre of the glacier moved faster than the margins. This *differential* motion is the capital discovery in relation to the motion of glaciers. It is claimed by both Agassiz and Forbes. It had, however, been previously distinctly stated, though not proved, by Bishop Rendu.

Laws of Glacier-Motion.—The term *differential motion* is a condensed expression for all the laws of glacier-motion. It asserts that the different parts of a glacier do not move together as a solid, but *move among themselves in the manner of a fluid.* A glacier moves like a fluid, though a very stiff, *viscous* fluid; its motion may therefore be rightly called *viscoid.* We will mention some of the most important laws of fluid motion, and show that glaciers conform to them.

1. *The Velocity of the Central Parts is greater than that of the Margins.*—This well-known law of currents, the result of friction of the fluid against the containing banks, was completely proved in the case of glaciers by the experiments of Agassiz and Forbes, and recently confirmed in the most perfect manner by Tyndall. A line of stakes, *a b c d e f g*, placed in a straight row across a glacier, becomes every day more and more curved, as seen in Fig. 46. The exact rate of motion for each stake is easily measured by the theodolite. The rate of the centre is often many times greater than that of the margins.

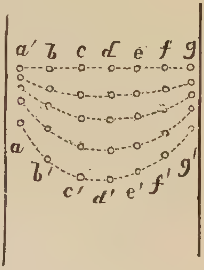


Fig. 46.

2. *The Velocity of the Surface is greater than that of the Bottom.*—This law of currents, which is the necessary result of friction on the bed, is more difficult to prove in the case of glaciers, because it is difficult to get a vertical section. The necessary observation was, however, successfully accomplished by Prof. Tyndall in 1857. We have already said (page 51) that glaciers conform to large but not to small inequalities of their channels: a glacier, therefore, passing by a narrow side-ravine will expose its whole thickness on the side. Prof. Tyndall, having found such a side exposure more than 140 feet vertical, placed three pegs in a vertical line, one near the top, one near the middle, and one at the bottom (Fig. 47, *a b c*). The vertical line became *more and more inclined* daily. The daily motion at top was six inches, in the middle 4.5 inches, and at the bottom 2.5 inches. Thus, glaciers, like rivers, slide on their beds and banks, producing erosion; but, also, the several layers, both horizontal and vertical, slide on each other.

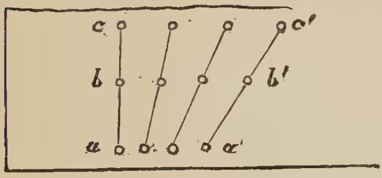


Fig. 47.

3. *The Velocity increases with the Slope.*—Fig. 48 represents the

surface-slope of the glacier *Du Géant*, *G*; the *Mer de Glace*, *M*; and the glacier *De Bois*, *B*; and their daily motion. The increase of velocity with the slope is evident.

4. *The Velocity increases with the Fluidity.*—The daily motion of

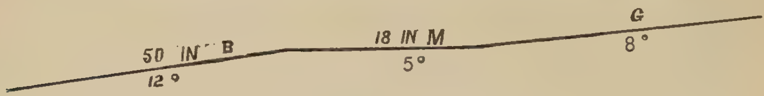


FIG. 48.

glaciers is greater in summer, when the ice is rapidly melting, than in winter; and in mid-day than at night.

5. *The Velocity increases with the Depth.*—In the Alps, where the thickness is 200 to 300 feet, the mean daily motion is one to three feet; but in Greenland, where the thickness is 2,000 to 3,000 feet, the daily motion, in spite of the much lower temperature, is in some cases 60 feet.[1]

6. *Fluid Currents conform to the Irregularities of their Channel*—Glaciers, like water-currents, conform to the inequalities of the bottom and sides of their channels. They have their shallows and their deeps, their narrows and their lakes, their cascades, their rapids, and their tranquil portions. Fig. 49 shows a glacier running through a narrow gorge into a wide lake of ice, and again through another gorge. There is this difference, however, between a glacier and a water-current, viz., that, while the latter conforms to even the *minutest and sharpest* outlines, the former conforms only to the *larger or more gentle.* In this, a glacier acts like a stiff, viscous fluid.

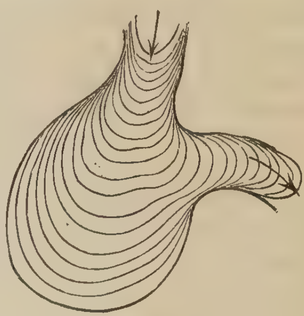


FIG. 49.

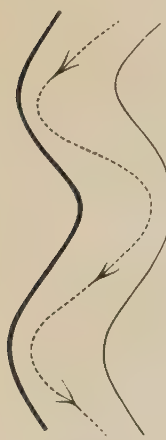


FIG. 50.

7. *The Line of Swiftest Motion is more sinuous than the Channel.*—We have already seen that this is true of rivers (page 21). The line of swiftest current is reflected from side to side, increasing the curves by erosion. The same has been recently proved by Tyndall to be the case with glaciers. Fig. 50 represents a portion of a sinuous glacier, like the Mer de Glace: the dotted line represents the line of swiftest motion.

[1] Helland, *Journal of Geological Society*, vol. xxxiii., p. 142, *et seq.*

Theories of Glacier-Motion.

There are few subjects connected with the physics of the earth which have excited more interest than that of glacier-motion. The subject is one of exceeding beauty, and not without geological importance. Passing over several very ingenious theories which have now been abandoned, the first theory which was conceived in the true inductive spirit, and which explains the differential motion, is that of Prof. James Forbes.

Viscosity Theory of Forbes.

Statement of the Theory.—According to Forbes, ice, though apparently so hard and solid, is really, to a slight extent, a viscous body. In small masses this property is not noticeable, but in large masses and under long-continued pressure it slowly yields, and will flow like a stiffly viscous fluid. In large masses like a glacier, this steady, powerful pressure is furnished by the immense weight of the superincumbent ice.

Argument.—It is evident that this theory completely accounts for all the phenomena of glacier-motion, even in their minutest details. A glacier, beyond all doubt, moves *like* a viscous body, but it is still a question whether it does so by virtue of a property of viscosity. The proposition that ice is a viscous substance seems at first palpably absurd. It is necessary, therefore, to show that this proposition is not so absurd as it seems.

The properties of solidity and liquidity, though perfectly distinct and even incompatible in our minds, nevertheless, in Nature, shade into one another in the most imperceptible manner. *Malleability*, *plasticity*, and *viscosity*, are intermediate terms of a connecting series. The idea which underlies all these expressions is that of *capacity of motion of the molecules among themselves without rupture:* the difference among them being the greater or less resistance to that motion. In the case of malleable bodies, like the metals, great force is required to produce motion; in plastic bodies, like wax or clay, less force is required; in viscous bodies, like stiff tar, motion takes place spontaneously but slowly; while in liquids it takes place freely and with little or no resistance. In all of these cases, if the pressure be sufficient, the body will change its form without rupture—in other words, will *flow.* Now, by increasing the mass we may increase the pressure to any extent. Therefore, all malleable, ductile, plastic, or viscous bodies, if in sufficiently large masses, will flow like water. Thus, a mass of lead, sufficiently thick, would certainly flow under the pressure of its own weight.

But solid bodies may be divided into two great classes, viz., bodies which are malleable, plastic, or viscous, and bodies which are *brittle;* the very idea of brittleness being that of total incapacity of motion

among the particles without rupture. Now, ice belongs to the class of brittle bodies. Forbes attempts to remove this difficulty by showing that many apparently brittle bodies will also flow under their own weight; for instance, pitch, so hard and brittle that it flies to pieces under a blow of the hammer, will, if the containing barrel be removed, flow and spread itself in every direction. So, also, molasses-candy, made quite hard and brittle, will still flow by standing. A remarkable pitch-lake, about three miles in circumference, occurs in Trinidad. The pitch is described as in constant, slow-boiling motion, coming up in the centre, flowing over to the circumference, and again sinking down. Yet this pitch, in small masses, would be called solid and brittle. Struck with a hammer, it flies to pieces like glass. In fact, the essential peculiarity of a stiff, viscous body, in which it differs from malleable or plastic bodies, is, that it yields *only* to *slowly-applied force.*

Forbes, therefore, thinks that glacier-ice is an exceedingly stiff, viscous substance, which, though apparently brittle in small quantities and to sudden force, yet, under the slow-acting but powerful pressure of its own weight, flows down the slope of its bed, squeezing through narrows and spreading out into lakes, conforming to all the larger and gentler inequalities of bed and banks, but not to the sharper ones. The velocity of motion is small in the same proportion as the viscous mass is stiff. The descent of the Mer de Glace from the cascade of the Glacier du Géant to the point of Glacier de Bois, a distance of ten miles, is 4,000 feet. Water, under these circumstances, would rush with fearful velocity. The glacier moves but two feet in twenty-four hours.

Regelation Theory of Tyndall.

If ice be indeed a viscous body, then there seems no reason why it should not yield to pressure even in small masses, if the pressure be sufficiently slowly graduated. In the hands of a skillful experimentalist it ought to exhibit this property. Prof. Tyndall tried the experiment. Masses of ice of various forms were subjected to slowly-graduated, hydrostatic pressure. In every case, however slowly graduated the pressure, the ice broke; but if the broken fragments were pressed together, they reunited into new forms. In this manner, ice in the hands of Prof. Tyndall proved as plastic as clay: spheres of ice (*a*, Fig. 51) were flattened into lenses (*b*), hemispheres (*c*) were changed into bowls (*d*), and bars (*e*) into semi-rings (*f*). He even asserts that ice may be moulded into any desirable form; e. g., into vases, statuettes, rings, coils, knots, etc. Here, then, we have a power of being moulded such as was not dreamed of before; but this power was not dependent on a property of viscosity, but upon another property long known, but only recently investigated by Faraday, viz., the property of *regelation.*

Regelation.—If two slabs of ice be laid one atop of the other, they soon freeze into a solid mass. This will take place not only in cold weather, but in midsummer, or even if boiling water be thrown over the slabs. If a mass of ice be broken to pieces, and the fragments be pressed, or even brought in contact with one another, they will quickly unite into a solid mass. Snow pressed in the warm hand, though con-

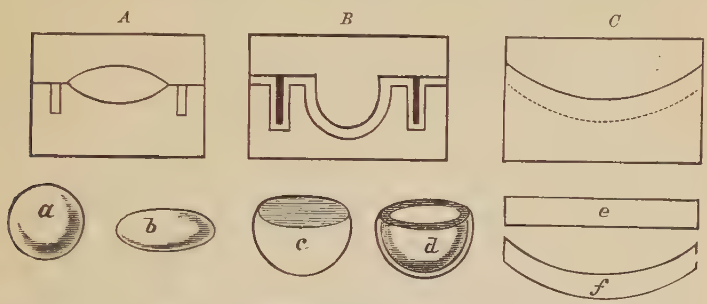


FIG. 51.—*A B C*, moulds; *a c e*, original forms of the ice; *b d f*, the forms into which they were moulded.

stantly melting, gradually becomes compacted into solid ice. This very remarkable but imperfectly understood property of ice completely explains the phenomena of moulding ice by experiment. By this property the broken fragments reunite in a new form as solid as before. We may possibly call this property of moulding under pressure *plasticity* (although it is not true plasticity, since it does not mould without rupture, but by *rupture and regelation*); but it cannot in any sense be called *viscosity*, for the true definition of viscosity is the property of *yielding under tension*—the property of *stretching* like molasses-candy, or melted glass; but ice in the experiments, according to Tyndall, did not yield in the slightest degree to tension. In the experiment, if, instead of placing the straight bar at once into the curved mould, it had been placed successively in a thousand moulds, with gradually-increased curvature, or, still better, if placed in a straight mould, and this mould, while under pressure, curved slowly, then there would have been no sudden visible ruptures, but an infinite number of small ruptures and regelations going on all the time. *The ice would have behaved precisely like a viscous body.* Now, this is precisely what takes place in a glacier.

Application to Glaciers.—A glacier, on account of its immense mass, is, *in its lower parts*, under the immense pressure of its own weight tending to mould it to the inequalities of its own bed, and *in every part* under a still more powerful pressure—a pressure proportioned to the height of the head of the glacier—urging it down the slope of its bed. Under the influence of this pressure the mass is continually yielding by

fracture, but again uniting by regelation. By this constant process of *crushing*, *change of form*, and *reunion*, the glacier behaves like a plastic or viscous body; though of true plasticity or true viscosity there is, according to Tyndall, none. In fact, we have in the phenomena of glaciers the most delicate test of viscosity conceivable; but we find the glaciers will not stand the test. For instance, the slope of the Mer de

FIG. 52.

Glace at one point changes from 4° to 9° 25′ [1] (Fig. 52), and yet the glacier, although moving but two feet a day, cannot make this slight bend without rupture; for at this point there are always large transverse fissures which heal up below by pressure and regelation. In another place the glacier is similarly broken by passing an angle produced by a change of slope of only 2°. It seems almost impossible that a body having the slightest viscosity should be fractured under these circumstances. Tyndall concludes, therefore, that the motion of glaciers is *viscoid*, but the body is *not viscous*—the viscoid motion being the result, not of the property of viscosity, but of fracture and regelation.

Comparison of the Two Theories.—Forbes's theory supposes motion among the *ultimate* particles *without rupture*. Tyndall's supposes motion among *discrete* particles *by rupture, change of position, and regelation*. The undoubted viscoid motion is equally explained by both: by the one, by a property of *viscosity*; by the other, by a property of *regelation*.

Conclusion.—It seems almost certain that both views are true, and that both properties are concerned in glacial motion. Recent observations and experiments have shown an undoubted viscosity in ice—especially in ice containing much inclosed and dissolved air, as is the case with glacier-ice. Ice boards supported at the two ends gradually bend into an arc under their own weight. Cylinders of snow compacted into ice may be bent in the hand to a semicircle without rupture.[2]

Structure of Glaciers.

There are two points connected with the structure of glaciers which require notice, viz., the *veined structure* and the *fissures*.

Veined Structure.—The ice of glaciers is not homogeneous, but consists of white vesicular ice (white because vesicular), banded, often very beautifully, with solid transparent blue ice (transparent blue because solid), the banding sometimes so delicate that a hand-specimen looks

[1] Tyndall, "Glaciers of the Alps."

[2] Aitkin, *American Journal of Science*, vol. v., p. 305, third series. See APPENDIX to this volume.

like striped agate. These *blue veins* are not continuous planes, but apparently very *flat lenticular* in shape, varying in thickness from a line to several inches, and in length from a few inches to several feet. Their direction being parallel to one another, they give a stratified or cleavage structure to the glacier, and, in melting, the glacier often splits or cleaves along these planes. According to Prof. Forbes, looking upon the glacier as a whole, we may regard the strata as taking the form represented by the subjoined figures. In a section parallel to

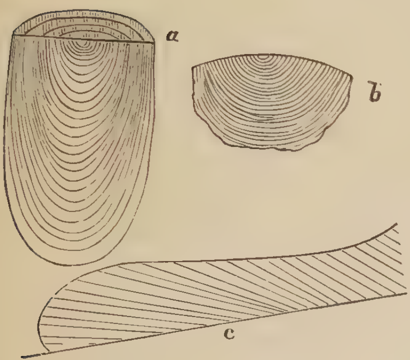


FIG. 53.—Sections of a Glacier.

FIG. 54.—Ideal Diagram, showing Structure of Glaciers (after Forbes).

the surface (Fig. 53, *a*), the strata outcrop in the form of loops. A cross-section (Fig. 53, *b*) shows them lying in troughs, and a longitudinal vertical section (Fig. 53, *c*) shows the manner in which they dip. Fig. 54 is an ideal glacier cut in several directions, and combining in one view the three sections given above. It is generally impossible to trace the veins around from side to side. Sometimes they are most distinct on the margins, and then are called *marginal veins;* sometimes at the point of the loop—*transverse veins;* sometimes tributaries running together, as in the figure (Fig. 54)—the interior branches of the two loops coalesce, and are flattened against one another, and form *longitudinal veins.*

Fissures.—These are also *marginal*, *transverse*, and *longitudinal.* The marginal fissures are shown in Fig. 40; they are always at right angles to the marginal veins.

Theories of Structure.

Fissures.—There can be no doubt that the great fissures or crevasses are produced by *tension* or *stretching*, and that their direction is always at right angles to the line of greatest tension. Thus the *transverse* fissures are produced by the stretching of the glacier in passing over a salient angle. The *marginal* fissures are produced by the dragging or pulling of the swifter central portions upon the slower marginal portions. It has been proved by Hopkins, the English physicist and geologist, that the line of greatest tension from this cause would be inclined 45°, with the course of the glacier as shown by the arrows (Fig. 55).

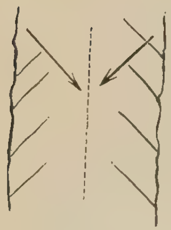


Fig. 55.

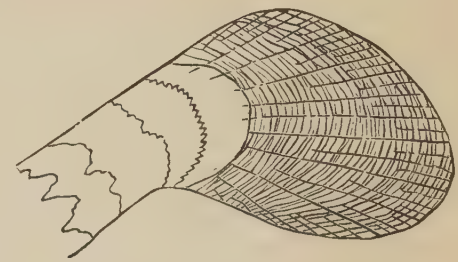


Fig. 56.

The fissures should be at right angles to these lines, and, therefore, also inclined 45° with the margin, and running upward and inward. The longitudinal fissures are best seen where a glacier runs through a narrow gorge out on an open plain. The *lateral* spreading of the glacier causes it to crack longitudinally (Fig. 56). Fig. 57 is a longitudinal vertical section of the same.

Veined Structure.—Tyndall has shown conclusively that veins are always at right angles to the line of greatest pressure, and that, therefore, they are produced by *pressure*. Thus fissures and veins, being produced by opposite causes—one by tension and the other by pressure—are found under opposite conditions. Thus as transverse fissures are produced by the longitudinal stretching of a glacier passing over a *salient* angle, so transverse veins are formed by the longitudinal compression of a glacier passing over a *reëntering* angle. Fig. 57 is a section of the Rhône glacier (Fig. 56), showing the crevasses (*c c c*)

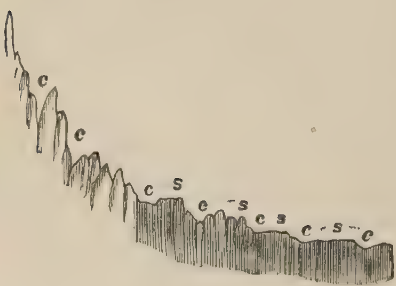


Fig. 57.

produced by the steep declivity, and the veined structure (*s s s*) produced by the compression consequent upon the change of angle on coming out on the plain. The relation of crevasses and vein-structure is still better shown in the ideal section (Fig. 58).

Again, as marginal fissures are produced by the pulling of the central portions upon the lagging margins *behind*, so the marginal veins are produced by the crowding or pushing of the swifter central parts upon the marginal parts *in front* (Fig. 59). The marginal veins are, therefore, inclined to the margin about 45°, but pointing inward and *downward*, and, therefore, at right angles to the crevasses. The relation of these to one another is shown in Fig. 60.

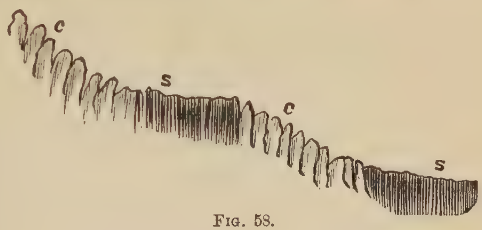


Fig. 58.

Finally, as longitudinal fissures are produced by lateral spreading (Fig. 56), so *longitudinal* veins are produced by lateral compression.

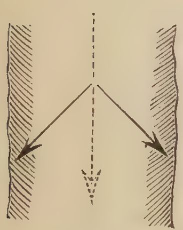


Fig. 59.

Fig. 60.

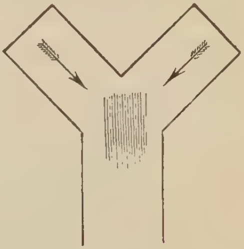


Fig 61.

This is best seen where two tributaries meet at high angle (Fig. 61)—for instance, where the Glacier du Géant and the Glacier de Léchaud form the Mer de Glace (Fig. 41). All these facts have been experimentally illustrated by Tyndall.

Physical Theory of Veins.—There is little doubt that veins are formed by pressure at right angles to the direction of the veins; but *how* pressure produces this structure is very imperfectly understood. Probably at least a partial explanation is contained in the following proposition: 1. White vesicular ice by powerful pressure is crushed, the air escapes, and the ice is refrozen into solid blue transparent ice. 2. Ice being a substance which *expands* in freezing, and, therefore, contracts in melting, its freezing and melting point is *lowered by pressure*. Therefore, ice at or near 32° Fahr. is *melted* by pressure. Now, the glacier is under powerful pressure of its own weight, and the stress of

this pressure is ever changing from point to point by the changing position of the particles produced by the motion. Thus the glacier in places is ever melting under pressure, and again refreezing by relief of pressure. The melting discharges the air-bubbles, and, in refreezing, the ice is blue. 3. No substance is perfectly homogeneous, and of equal strength in all parts; therefore, this crushing and melting, and consequent conversion of white into blue ice, take place *irregularly* in spots. 4. As ice of a glacier acts like a viscous substance, the final effect of pressure would be to flatten these spots, both white and blue, in the direction of greatest pressure, and *extend* them in a direction at right angles to the pressure, and thus create bands in this direction. 5. Differential motion would also tend to bring the veins into the direction indicated by Forbes.

Floating Ice—Icebergs.

We have already seen (page 47) that at a certain latitude, varying from 46° in South America to about 65° in Norway, glaciers touch the surface of the ocean. Beyond this latitude, they run out to sea often to great distances. By the buoyant power of water, assisted by tides and waves, these projecting floating masses are broken off, and accumulate as immense ice-barriers in polar seas, or are drifted away by currents toward the equator. Such floating fragments of glaciers are called *ice-*

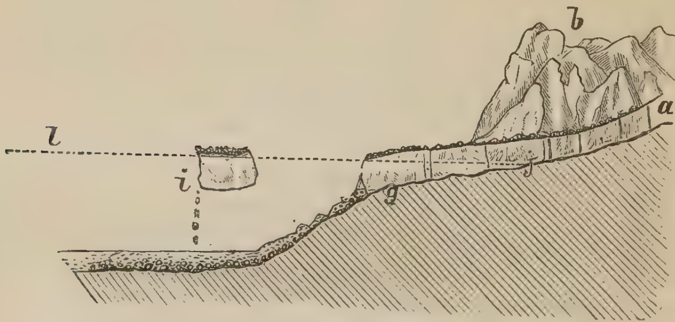


Fig. 62.—Formation of Icebergs.

bergs. Fig. 62 is an ideal section, through a glacial valley, in which $a\,g$ is the glacier, b the cliffs beyond, $l\,j$ the sea-level, and i an iceberg.

The principal source of the icebergs of the north Atlantic is the coast of Greenland. This country is an elevated table-land, sloping in every direction to a coast deeply indented like Norway, with alternate deep fiords and jutting headlands. The whole table-land is completely covered with an *ice-sheet*, probably several thousand feet thick, moving slowly seaward, and discharging through the fiords as immense

glaciers,[1] which, as already explained, form icebergs. In this remarkable country no water falls from the atmosphere except in the form of snow, and *all the rivers are glaciers.* The geological effects of such a moving ice-sheet may be easily imagined. The whole surface of the country rock must be polished and scored, the general direction of the striæ being *parallel over large areas.*

The antarctic continent is probably similarly, and even more thickly, ice-sheeted, for the humid atmosphere of that region is very favorable to the accumulation of snow and ice. Captain Wilkes found an impenetrable ice-barrier, in many places 150 to 200 feet high, for 1,200 miles along that coast. From this ice-barrier, icebergs separate and are drifted toward the equator.

The formation of icebergs in polar regions, and their drifting into warmer latitudes, to be melted there, is evidently a necessary consequence of the great *law of circulation*, for otherwise ice would accumulate without limit in these regions.

General Description.—The *number* of icebergs accumulated about polar coasts is almost inconceivable. Scoresby counted 500 at one view. Kane counted 280 of the first magnitude at one view. They are often 200 and sometimes even 300 feet high, and the mass above

Fig. 63.

water 66,000,000 cubic yards (Dr. Rink). As the specific gravity of ice is 0.918, if these were solid ice, there would be but one-twelfth above water; but as glacier-ice is somewhat vesicular, there is about one-seventh above water. The *thickness* of some of these icebergs must therefore be 2,000 to 3,000 feet, and their *volume* near 500,000,000 cubic yards, which is about equivalent to a mass one mile square, and 500 feet thick. Under the influence of the melting power of the sun un-

[1] Dr. Rink, "Archives des Sciences," vol. xxvii., p. 155.

equally affecting different parts, they assume various and often strange forms. The accompanying figure (Fig. 63) gives the usual appearance in the northern Atlantic. Those separated from the antarctic barrier present, before they have been much acted upon by the sun, a much more regularly prismatic appearance. Fig. 64 gives the appearance of

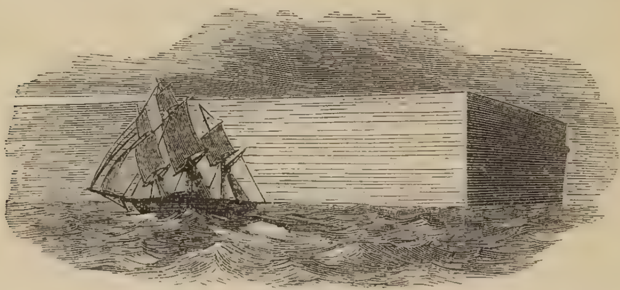


FIG. 64.

one of these prismatic blocks or tables, 180 feet high, seen by Sir James Ross in the antarctic seas.

Icebergs as a Geological Agent—Erosion.—The polishing and scoring effects of the ice-sheets and of their discharging glaciers must, of course, extend over the sea-bottoms about polar coasts as far as the glaciers touch bottom, which, considering their immense thickness, must be for considerable distance (Fig. 62, *j* to *g*). This, however, is glacier agency rather than iceberg agency. On being separated they float away, and are carried by currents with their immense loads of earth and bowlders, amounting often to 100,000 tons or more, as far as 40° or even 36° latitude, where, being gradually melted, they drop their burden. If the water be not sufficiently deep, they ground, and being swayed by waves and tides they chafe and score the bottom in a somewhat irregular manner; or, packing together in large fields, and urged onward by powerful currents, they may possibly score the bottom over considerable areas somewhat in the manner of glaciers. A large iceberg will ground in water 2,000 and 2,500 feet deep; they have been found by James Ross actually aground in 1,560 feet of water off Victoria Land. A true glaciated surface, however, cannot be produced by icebergs.

Deposits.—The bottom of the sea about polar shores is found deeply covered with materials brought down by glaciers and dropped by icebergs (Fig. 52). Again, similar materials are carried by icebergs as far as these are drifted by currents, and spread on the bottom of the sea everywhere in the course of these currents. Where stranded icebergs accumulate, as on the banks of Newfoundland, large quantities of such materials are deposited. These banks are in fact supposed to

have been formed in this way. Such deposits have not been sufficiently examined; they are probably somewhat similar to those of glaciers, exhibiting, however, some signs of the sorting power of water. Balanced stones or bowlders in insecure positions can hardly be left by icebergs.

Shore-Ice.

In cold climates the freezing of the surface of the water forms sheets of ice many inches or even feet thick, and of great extent, about the shores of rivers, bays, and seas. They often inclose stones and bowlders of considerable size, and when loosened in spring from the shore they bear these away, and again drop them at considerable distances from their parent rock. Also such sheets packed together in large masses, and driven ashore by river and tidal currents, and chafed back and forth by waves, produce effects on the shore-rocks somewhat similar to the scoring, polishing, and even the *roches moutonnées* of glacier-action. On a rising or on a subsiding coast such scorings and polishings may extend over wide areas, and thus simulate true glacial action. These effects are well seen on the shores of the St. Lawrence River and Gulf.

The importance of the study of ice-agencies will be seen when we come to explain the phenomena of the Drift or Glacial period.

Comparison of the Different Forms of the Mechanical Agencies of Water.

Rivers and glaciers are constantly cutting down all lands, bearing away the materials thus gathered, and depositing them on the sea-margins. Acting alone, therefore, their effect must be to diminish the height and to extend the limits of the land. Ocean agencies, on the other hand, by tides and currents bear away to the open sea the materials brought down from the land, and thus tend to prevent marginal accumulations; and by waves and tides constantly eat away the coast-line, and thus strive to extend the domain of the sea. Thus, while river and ocean agencies are in conflict with one another at the coast-line, the one striving to extend the limits of the land, and the other of the sea, yet they coöperate with each other in destroying the inequalities of the earth's surface, and are therefore called *leveling agencies.* Moreover, it is evident that the erosion of the land and the filling up of the seas are correlative, and one is an exact measure of the other. Now, we have seen (page 11) that the probable rate at which all continents are being cut down by rivers is about one foot in 4,500 to 5,000 years. But since the ocean is about three times the extent of the land, this spread evenly over the bottom of the sea would make a stratum about four inches thick. Therefore, we conclude that, neglecting the destructive effects of waves and tides on the coast-line, which, according to

Phillips,[1] are small in amount compared with general erosion of the land-surface, we may say that stratified deposits are now forming, or the ocean-bed filling up, at the rate of about four inches in 5,000 years.

SECTION 4.—CHEMICAL AGENCIES OF WATER.

Subterranean Waters, Springs, etc.

As we have already seen (page 9), of the rain which falls on any hydrographical basin, a part runs from the surface, producing universal erosion. A second part sinks into the earth, and, after a longer or shorter subterranean course, comes up as springs, and unites with the surface-water to form rivers; while a third portion never comes up at all, but continues by subterranean passages to the sea. This last portion is removed from observation, and our knowledge concerning it is very limited. But there are numerous facts which lead to the conviction that it is often very considerable in amount. In many portions of the sea near shore, springs, and even large rivers, of fresh water, are known to well up. Thus, in the Mediterranean Sea, "a body of fresh water fifty feet in diameter rises with such force as to cause a visible convexity of the sea-surface."[2] Similar phenomena have been observed in many other places in the same sea, and also in the Gulf of Mexico near the coast of Florida, among the West India isles, and near the Sandwich Islands. Besides the last mentioned, there is still another portion of subterranean water existing permanently in every part of the earth far beneath the sea-level, filling fissures and saturating sediments to great depths, and only brought to the surface by volcanic forces. This, in contradistinction from the constantly-circulating meteoric water, may be called *volcanic water.*

Springs.—The appearance of subterranean waters upon the surface constitutes *springs.* They occur in two principal positions, viz.: 1.

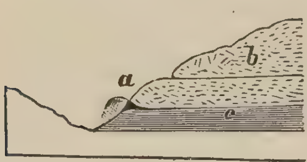


FIG. 65.—Hill-side Spring.

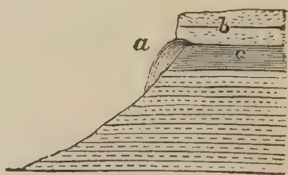


FIG. 66.

Upon *hill-sides,* just where porous, water-bearing strata such as *sand* outcrop, underlaid by impervious strata like *clay;* 2. On *fissures,* penetrating the country rock to great depth.

Most of the *small springs* occurring everywhere belong to the first class. The figure (Fig. 65) represents a section of a hill composed mostly

[1] Phillips, "Life on the Earth," p. 131.

[2] Herschel's "Physical Geography."

of porous strata, *b*, but underlaid by impervious clay stratum, *c*. Water falling upon the surface sinks through *b* until it comes in contact with *c*, and then by hydrostatic pressure moves laterally until it emerges at *a*. Sometimes this is a geological agent of considerable importance, modifying even the forms of mountains, and producing land-slips, etc. Thus the Lookout and Raccoon Mountains, in Tennessee, are table-mountains of nearly horizontal strata, separated by erosion-valleys. These mountains are all of them capped by a sandstone stratum about 100 feet thick, underlaid by shale. The water which falls upon the mountain emerges in numerous springs all around where the sandstone cap comes in contact with the underlying shale. The sandstone is gradually undermined, and falls from time to time, and thus the cliff remains always perpendicular (Fig. 66).

Large springs generally issue from fissures. Water passing along the porous stratum *b*, perhaps from great distance, and prevented from rising by the *overlying* impervious stratum *c*, coming in contact with a fissure, immediately rises through it to the surface at *a* (Fig. 67).

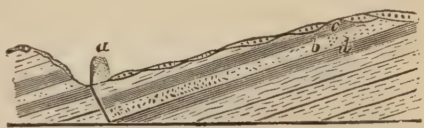


Fig. 67.—Fissure-Spring.

Artesian Wells.—If subterranean streams have their origin in an elevated region, *a d*, composed of regular strata dipping under a lower flat country, *c*, then the subterranean waters passing along any porous stratum, as *a* (Fig. 68), and confined by two impermeable strata, *b* and *d*, will be under powerful hydrostatic pressure, and will, therefore, rise to the surface, perhaps with considerable force, if the stream be tapped by boring at *c*. Borings by which water is obtained in this manner are called artesian wells, from the French province Artois, where they were first successfully attempted. The source of the water may be 100 miles or more distant from the well. Some of these wells are very deep. The Grenelle artesian in Paris is 2,000 feet deep. At the moment of tapping the stream, a powerful jet was thrown 112 feet high. One in Westphalia, Germany, is 2,385 feet deep; one at St. Louis, 3,843 feet; one at Louisville, Kentucky, 2,852. In parts of Alabama and California, the principal supply of water for agricultural purposes is drawn from these wells.

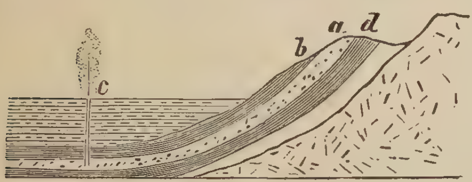


Fig. 68.—Artesian Well.

Thus there is on all coasts a constant flowing of water, both superficial and subterranean, into the sea. Their relative amount it is impos-

sible to determine. Much depends upon the configuration of the country and the nature of the strata. The heavy hydrostatic pressure to which subterranean water is subjected, especially in elevated countries, brings the larger portion of it to the surface as springs. But, in limestone regions (this rock being affected with frequent and large fissures, and open subterranean passages, as will be hereafter explained), large subterranean rivers often exist, and these, even after coming to the surface, are often reëngulfed, and finally reach the sea by subterranean passages. The largest springs, therefore, generally occur in limestone countries. From the Silver Spring, in Florida, issues a stream navigable for small steamers up to the very spring itself. The country for sixty miles around is entirely destitute of superficial streams, the whole drainage being subterranean, and coming up in this spring.[1]

Chemical Effects of Subterranean Waters.—We have already seen (page 6) how atmospheric water disintegrates rocks, dissolving out their soluble parts, and reducing their unsoluble parts to soils. Springs, therefore, always contain these soluble matters. In granite regions they contain potash ; in limestone regions they contain lime, and are called *hard ;* in other cases they contain salt, and are *brackish ;* when the saline ingredients are unusual in quantity, or in kind, they are called *mineral* waters.

Limestone Caves.—In most rocks, the insoluble part left as soil is far the largest, only a small percentage being dissolved ; but in the case of limestone the whole rock is soluble. Therefore, in limestone regions, percolating waters dissolve the limestone, hollow out *open passages*, and form immense *caves.* Water charged with limestone, dripping from the roofs and falling on the floors of these caves, deposit their limestone by evaporation, and form *stalactites* (Fig. 69), *a a*, and *stalagmites*, *b b*, which, meeting each other, form *limestone pillars*, *c c*. The great Mammoth Cave, in Kentucky ; Wier's Cave, in Virginia, and Nicojack Cave, in Tennessee, are familiar examples. As might be expected, subterranean rivers are often found in these caves. This is the case in the Mammoth Cave, and in Nicojack Cave.

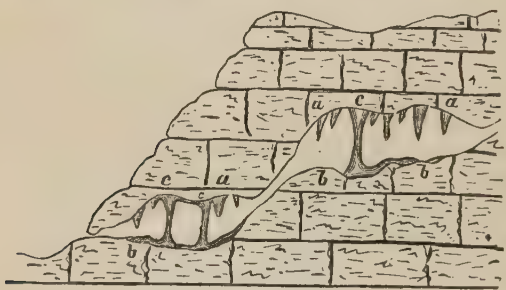


Fig. 69.—Limestone Cave.

[1] The exceptional transparency of limestone waters is due to the property, possessed by lime in a remarkable degree, of flocculating and precipitating clay sediments.

Chemical Deposits in Springs.

Deposits of Carbonate of Lime.—We have just seen that ordinary subterranean waters in limestone districts, and, therefore, containing small quantities of carbonate of lime, deposit this substance *only very slowly by drying*, as stalactites and stalagmites; but in *carbonated springs* in limestone districts a very rapid deposit of lime carbonate often occurs.

Explanation.—In order to understand this, it is necessary to remember: 1. That lime carbonate is insoluble in pure water, but soluble in water containing carbonic acid; 2. That the amount of carbonate dissolved is proportionate to the amount of carbonic acid contained; 3. That the amount of carbonic acid which may be taken in solution by water is proportionate to the pressure.

Now, there are two sources of carbonic acid, viz., atmospheric and subterranean. All water contains carbonic acid from the atmosphere, and will, therefore, dissolve limestone, but this deposits only slowly by drying, as already explained. But in many districts, especially in volcanic districts, there are abundant subterranean sources of carbonic acid. If subterranean waters come in contact with such carbonic acid, being under heavy pressure, they will take up a large quantity of this gas; and if such water comes to the surface, the pressure being removed, the gas will escape in bubbles. This is a *carbonated spring.* If, further, the subterranean waters, thus highly charged with carbonic acid, come in contact with limestone rocks, or rocks of any kind containing lime carbonate, they will dissolve a proportionably large amount of this carbonate; and when they come to the surface, the escape of the carbonic acid causes the lime carbonate to deposit abundantly. Thus around *carbonated* springs in *limestone* districts, and along the course of the streams which issue from them, are generally found extensive deposits of this substance. Being found mostly in volcanic regions, these springs are commonly hot.

Kinds of Materials.—The material thus deposited is usually called travertine, but is very diverse in appearance. If the deposit is quiet, the material is *dense;* if tumultuous, the material is *spongy;* if no iron is present, it is *white* like marble; but if iron be present, its oxidation colors it yellow, brown, or reddish. If the amount of iron be variable, the stone is beautifully *striped.* If objects of any kind, branches, twigs, leaves, are immersed in such waters, they are speedily incrusted, often in the most beautiful manner.

Examples of such deposits are found in all countries. At the baths of San Vignone, Italy, a carbonated spring issuing from the top of a hill has covered the hill with a stratum of white, compact travertine 250 feet thick. In the conduit-pipe which leads the water to the baths, the

deposit accumulates six inches thick every year. A similar deposit of travertine occurs at the baths of San Filippo. At this latter place, beautiful *fac-similes* of medallions, coins, etc., are formed by placing these objects of art in the spray of an artificial cascade. In Virginia, around the "Old Sweet" and the "Red Sweet" Springs, and in the course of the stream which flows from them for several miles, a brownish-yellow deposit of travertine has accumulated to the depth of at least thirty feet. The spray of Beaver Dam Falls, about three miles below the springs, incrusts every object in its reach with this deposit.

In California, all about the shores of Lake Mono, abundance of beautiful and strangely-branched coralline forms are found, which have evidently been formed in a somewhat similar way. In the region of the Yellowstone Park, deposits of travertine from waters of hot springs running down a steep incline, in a succession of cascades, assume the most beautiful forms, as shown in the accompanying figure, taken from Hayden.

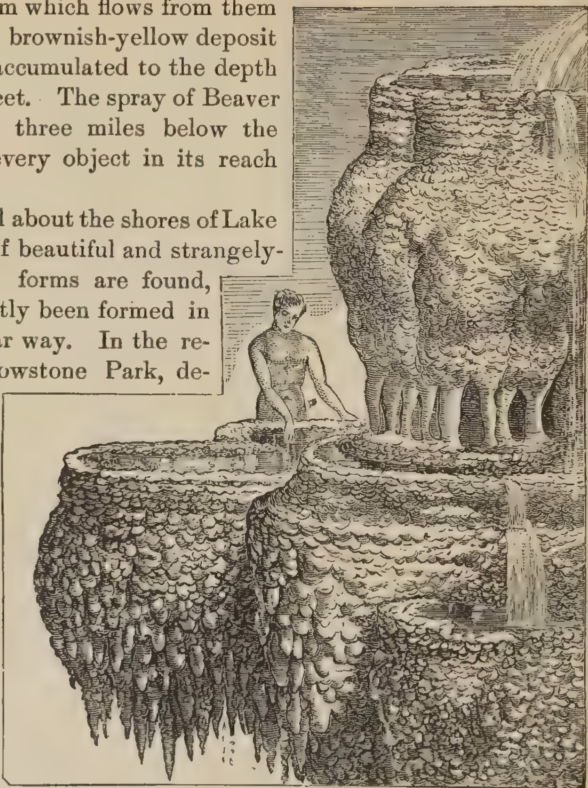


FIG. 70.—Deposits from Carbonated Springs.

Deposits of Iron.—Iron carbonate, like lime carbonate, is to some extent soluble in water containing carbonic acid. Subterranean waters, therefore, which always contain atmospheric carbonic acid, when they meet this carbonate, will take up a small quantity in solution. Such waters are called *chalybeate.* On coming to the surface the iron gives up its carbonic acid, is peroxidized, becomes insoluble, and is deposited. As the presence of organic matter is usually necessary to bring the iron into a soluble condition, the full discussion of this very interesting subject is reserved until we take up organic agencies.

Deposits of Silica.—Silica is soluble in alkaline waters, especially if the waters be *hot.* Such waters reaching the surface and cooling, de-

posit the silica in great abundance, often at first in a gelatinous condition, but drying to a white porous material called *siliceous sinter*. Examples of such deposits are found in all geysers, as in those of Iceland, and in the Steamboat Springs in Nevada, and especially in the wonderful geysers of Yellowstone Park. Such deposits are confined to volcanic regions, the volcanic rocks furnishing both the alkali and the heat. We will discuss these again under Igneous Agencies.

Deposits of Sulphur and Gypsum.—Springs containing sulphide of hydrogen (H_2S), usually called *sulphur-springs*, sometimes deposit sulphur by oxidation of the hydrogen ($H_2S+O=H_2O+S$), and sometimes gypsum. This latter deposit is caused by the more complete oxidation of the sulphide of hydrogen, forming sulphuric acid ($H_2S+4O=H_2SO_4$), and the reaction of this acid on lime carbonate held in solution in the same water.

Chemical Deposits in Lakes.

Salt Lakes and Alkaline Lakes.—Salt lakes may be formed either —1. By the *isolation of a portion of sea-water* in the elevation of sea-bottom into land; or, 2. By *indefinite concentration of river-water* in a lake without an outlet. Thus, the Dead Sea, Lake Elton, and the brine-pools of the Russian steppes, are probably concentrated remains of isolated portions of the sea,[1] for their waters are highly-concentrated mother-liquors of sea-water, having a composition very similar to the mother-liquors of the *salt-maker*. The Caspian Sea, on the other hand, although elevated lake-margins show that much of its waters has dried away, is still much fresher than sea-water. This fact, together with the composition of its waters, is usually supposed to indicate that it has been formed by the simple concentration of the waters of a once fresh lake.[2] Yet there are some evidences, as we shall see hereafter, of this sea having been once connected with the Black and with the Arctic Ocean. The composition of the waters of the Great Salt Lake of Utah would seem to indicate its origin in the isolation of sea-water; but there are also some evidences of its once having had an outlet, in which case it must have been fresh, or at least brackish.[3]

Alkaline lakes can only be formed by the second way. Both salt and alkaline lakes, therefore, may be formed by indefinite concentration of river-water in a lake without outlet. Whether the one or the other is formed depends on the composition of the river-water. If alkaline chlorides predominate, a salt lake will be formed; but if alkaline carbonates, an alkaline lake. Such alkaline lakes are found in Hungary, in Lower Egypt, and in Persia. In our own country, Lake Mono, fifteen miles long and twelve miles wide, and Lake Owen, of at

[1] Bischof, "Chemical and Physical Geology," vol. i., p. 396.
[2] Ibid., p. 91. [3] Gilbert, "Wheeler Report for 1872," p. 49.

least equal dimensions, are examples of alkaline lakes. The waters of Lake Mono consist principally of a strong solution of *carbonate of soda*, with a little carbonate of lime and borate of soda.[1]

Conditions of Salt-Lake Formation.—Spring and river waters always contain a small quantity of saline matter derived from the rocks and soils. Suppose, then, we have a lake supplied by rivers: 1. If the supply of water by rivers is greater than the loss by evaporation from the lake-surface, then the water will rise until, finding an outlet in the rim of the lake-basin, it flows into the sea. In this case the lake will remain *fresh*, or the quantity of saline matter will be inappreciable. But if, on the other hand, the loss by evaporation is greater than the supply by rivers, the lake will decrease in extent, and therefore in evaporating surface, until an equilibrium is established. Now all the saline matters constantly leached from the earth accumulate in the lake without limit; the lake, therefore, must eventually become saturated with saline matter, and afterward begin to deposit salt. It is evident, then, that whether a lake is fresh or salt depends upon whether or not it has an outlet, and this latter depends upon the relation of supply by rivers to loss by evaporation. Lakes are mostly fresh, because much more water falls on continents than evaporates from the same surface, the excess running back to the sea by rivers. It is only in certain parts of the continents, where the climate is very dry, that there is no such excess. In these regions alone, therefore, can salt lakes exist. Such regions occur in the interior of Asia, on the plateau of Mexico, in the basin of Utah, and in several other places.

Even in case a salt lake is originally formed by the isolation of a portion of sea-water, whether it remains a salt lake or gradually becomes fresh will depend upon the conditions we have already mentioned. For example: if the Mediterranean should be separated from the Atlantic at the straits of Gibraltar, it would not only remain a salt lake, but would diminish in area, and finally deposit salt. This we conclude, because the water of the Mediterranean seems to be a little more salt than that of the Atlantic. If, on the contrary, the Black Sea were separated from the Mediterranean, or the Baltic from the Atlantic, or the bay of San Francisco from the Pacific, the supply by rivers, in the case of these inland seas being greater than their loss by evaporation, they would rise until they found an outlet, and then would be gradually rinsed out, and become fresh. Lake Champlain was, in very recent geological time, an arm of the sea. When first isolated it was salt. It has become fresh by this process.

[1] The probability of Great Salt Lake having been produced by simple evaporation of river-water is increased by the difference in the composition of the waters of lakes in this general region. Where sedimentary rocks prevail, as in Utah, they are salt; where volcanic rocks prevail, as about Mono and Owen, they are alkaline.

Deposits in Salt Lakes.—The nature of the chemical deposits in salt lakes will depend upon the manner in which these lakes have been formed. We will take the simplest case, viz., that of a lake formed by the isolation of sea-water, and its concentration by evaporation. In this case the substance first deposited would be *gypsum;* for this substance is insoluble in a saturated brine, and therefore always deposits first in the artificial evaporation of sea-water in salt-making. Upon the gypsum would be deposited *salt.* Meanwhile, however, the rivers during their flood-season would bring down *sediments.* During the flood-season, the supply of water being greater than loss by evaporation, the deposit of salt or gypsum would cease; while during the dry season the deposit of sediment would cease, and the evaporation being now in excess, the deposit of salt would recommence. Thus the deposits in the bottom of salt lakes probably consist of alternations of salt and sediment, the whole underlaid by layers of gypsum. These views have been confirmed by observation. During the dry season Lake Elton deposits annually a considerable layer of salt. Wells dug near the margin of this lake revealed 100 alternations of salt and mud, the salt-beds being many of them eight or nine inches thick.[1] Most of the salt has already deposited; for the water of this lake is an almost pure *bittern.* The great predominance of chloride of magnesium in Dead Sea water shows that it is a mother-liquor, from which immense quantities of common salt have already been deposited. Similar alternations, therefore, no doubt exist in the bottom of this sea.[2] The *Great Salt Lake*, in Utah, is also a saturated brine depositing salt, as is proved by the incrustations of salt about its margin in dry seasons; but the deposit has not progressed so far in this case as in the preceding. The great extent to which the waters of this lake have dried away and become concentrated is further shown by *old lake-margins* far beyond the limits, and several hundred feet above the level, of the present shore-line. Similar phenomena are observed about other salt lakes, especially about the Caspian Sea (Murchison).

In the case of salt lakes, either formed entirely, or modified, by river-water, the deposits are probably much more complex and various—sometimes salt, sometimes carbonate of lime, and sometimes sulphate of lime. This subject, however, has been but little investigated.

Deposits are also sometimes formed in lakes which are not salt. For example: the Solfatara Lake, Italy, is formed by the accumulation of the water from warm carbonated springs, similar to those of San Filippo and San Vignone. In this lake, therefore, deposits of travertine are forming. Although these deposits take place in a lake, they properly belong to deposits from springs, since they do not take place by concentration.

[1] Bischof, "Chemical and Physical Geology," vol. i., p. 405. [2] Ibid., p. 400.

Chemical Deposits in Seas.

Concerning these little is known. It is certain, however, that all rivers carry to the sea carbonate of lime in solution, and some of them in considerable quantities. There is scarcely any river-water which contains less carbonate of lime than sea-water ; many rivers contain four times as much.[1] This carbonate of lime thus constantly carried into the sea must eventually deposit in some form. Usually, however, sea-water is kept below the saturating point for this substance, by its constant withdrawal by shells and corals, as will be explained under Organic Agency. But in shallow bays nearly cut off from the sea, or in salt lagoons on the sea-margin near the mouths of rivers in dry climates, and subject to occasional overflows by the sea and floodings by rivers, carbonate of lime and sulphate of lime may deposit by evaporation. At the mouths of many rivers, whose waters contain much carbonate of lime, as, for instance, the Rhine, the delta deposit is cemented into hard rock by means of this substance. On shores of coral seas, as upon the Keys of Florida, the coast of the West India Islands, and the islands of the Pacific, shore-material is consolidated into hard rock by the same means. On many shores in tropical regions, the waves, being driven up on flat beaches far inland, leave sea-water inclosed in shallow pools, which by evaporation give rise to calcareous deposits which are increased by the frequent alternate influx and evaporation of sea-water. Conglomerate rocks are thus forming at the present time in the Canaries and many other places.

CHAPTER III.

IGNEOUS AGENCIES.

THE agencies thus far considered tend to reduce the inequalities of the earth by cutting down the continents and filling up the seas. Their final effect, if unopposed, would be to bring the whole surface to one level, and thus to make the empire of the sea universal. This is prevented by igneous agencies, which tend, by elevation of land and depression of sea-bottoms, to increase the inequalities of the earth-surface, and thus to *increase the area and the height of the land*. All the different forms of igneous agency are connected with the interior heat of the earth. This must, therefore, be first considered.

SECTION 1.—INTERIOR HEAT OF THE EARTH.

Stratum of Invariable Temperature.—The mean surface temperature of the earth varies from 80° at the equator to nearly 0° at the poles.

[1] Bischof, "Chemical and Physical Geology," vol. i., p. 179.

The rate of decrease in passing from the equator to the poles is not the same in all longitudes; the isotherms, or lines joining places of equal mean temperatures, are therefore not parallel to the lines of latitude, but quite irregular. The mean temperature of the whole earth-surface is about 58°. There is also in every locality a *daily* and an *annual variation* of temperature. As we pass below the surface both the daily and annual variations become less, until they cease altogether. The *stratum of no daily variation* is but a foot or two beneath the surface; but the stratum of no *annual* variation, or *stratum of invariable temperature* in temperate climates, is about sixty to seventy feet deep. The temperature of the invariable stratum is nearly the mean temperature of the place. The *depth* of the invariable stratum depends upon the amount of annual variation; it is, therefore, least at the equator, and increases toward the poles. At the equator it is only one or two feet beneath the surface;[1] in middle latitudes about sixty feet, and in high latitudes probably more than 100 feet. It is, therefore, a spheroid more oblate than the earth itself. The temperature of the earth everywhere within this spheroid is unaffected by external changes.

Increasing Temperature of the Interior of the Earth.—Beneath the invariable stratum the temperature of the earth everywhere increases,

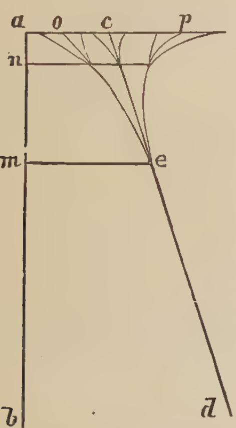


Fig. 71.

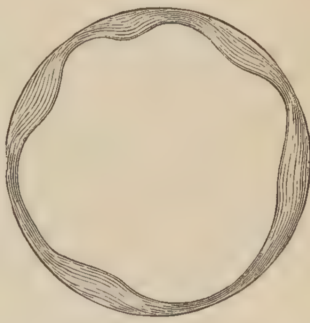


Fig. 72.

for all depths to which it has been penetrated, at an average rate of 1° for every 53 feet. This very important fact has been determined by numerous observations on the temperature of mines and of artesian wells in almost every part of the earth. All the facts thus far stated are graphically illustrated in the accompanying figure (Fig. 71), in which the line *a b* represents depth below the surface, and the diverging

[1] Humboldt, "Cosmos," Sabine's edition, vol. i., p. 165.

line $c\,d$ the increasing heat; m the invariable stratum; n the line of no daily variation; the curves $p\,e$, $c\,e$, $o\,e$, the temperatures in summer, autumn, and winter, respectively; the space $p\,e\,o$ the annual swing of temperature; and the smaller curves meeting on the line n, the daily variation or swing of temperature.

We have given the rate of increase as about 1° in 53 feet. It varies, however, in different places, from 1° in 30 feet to 1° in 90 feet. Except in the vicinity of volcanic action, this difference is probably due to varying *conductivity* of the rocks. The lines, or rather surfaces, which join places in the interior of the earth, having equal temperatures, may be called *isogeotherms*. If the rate of increase were everywhere the same, the isogeotherms would be regularly concentric; but, as this is not the case, they are irregular surfaces (Fig. 72), rising nearer the earth-surface, and closing upon one another where the conductivity is poor, and sinking deeper and separating where the conductivity is greater.

Constitution of the Earth's Interior.—From the facts given above it is probable that the temperature of the interior of the earth is very great. A rate of increase of 1° for every 53 feet would give us, at the depth of twenty-five or thirty miles, a temperature sufficient to fuse most rocks. Hence it has been confidently concluded by many, that the earth, beneath a comparatively thin crust of thirty miles, must be liquid. A crust of thirty miles on our globe is equivalent to a crust of less than one-tenth of an inch in a globe two feet in diameter. There are, however, many objections to this conclusion. The question of the interior constitution of the earth is one of extreme difficulty and complexity, and science is not yet in a position to solve it completely. Nevertheless, it can be proved that the solid crust must be much thicker than is usually supposed, if, indeed, there be any general interior fluid at all.

The argument for the interior fluidity of the earth, beneath a crust of only thirty miles, proceeds upon two suppositions, viz.: 1. That the *interior temperature increases at the same rate for all depths;* and, 2. That the *fusing-point* of rocks is *the same for all depths.* Now, neither of these can be true.

1. **Rate of Increase not uniform.**—Although we have spoken of 1° for *every* 30 feet or 50 feet or 90 feet, yet it must not be supposed that observation gives a uniform rate of increase at any place. On the contrary, the rate is sometimes faster and sometimes slower, depending on the conductivity of the rock penetrated, and on other causes little understood. The rate given is always an *average.* In other words, observation gives the *fact* of increase, but not the *law.* We are thus thrown back on general reasoning.

If two bars, one a good conductor, like metal, and the other a bad conductor, like charcoal, be heated red hot at one end, and the rate of

decreasing temperature—fall of heat—toward the other be observed, it will be found that the rate is very rapid in the case of the charcoal; so that a temperature of 60° is reached at the distance of two or three inches, while in the case of the metal the rate of decrease is much slower, and 60° is only reached at a distance of several feet. Conversely, the rate of *increase*, or *rise*, in passing toward a source of heat, is rapid in the case of the bad conductor, and slow in the case of the good conductor. Now, the average density of materials at the surface of the earth is about 2.5, but the average density of the whole earth is more than 5.5; therefore the density of the central portions must be much more than 5.5. It has been estimated at 16.27.[1] There can be no doubt, therefore, that the density of the earth increases toward the centre; and as this increase is probably largely the result of pressure, it is probably somewhat regular. Whatever be the cause, the effect would be to *increase the conductivity for heat*, and therefore to *diminish* the rate of increasing temperature. Thus it follows that, though in an homogeneous globe the melting-point of rocks (3,000°) would be reached at the depth of 30 miles, yet, in a globe increasing in density toward the centre, we must seek this temperature at a greater depth.

If *A B* (Fig. 73), representing *depth* from the surface *S S*, be taken as absciss, and *heat* be represented by ordinates, then, in an homogeneous earth, *C D* would represent uniform increase of heat, and the heat ordinate of 3,000°, *m m*, would be reached at the depth of *A m* = thirty miles. But in an earth increasing in density, and, therefore, in conductivity, the rate would not be uniform, but gradually decreasing. This would be represented, not by a straight line, *C D*, but by a curved line, *C E;* and the ordinate of 3,000° would not be reached at thirty miles, but at a much greater depth—say at *m′*, of fifty miles.

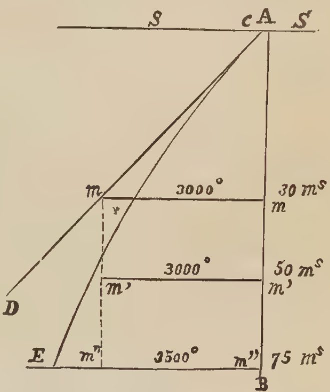


FIG. 73.

2. Fusing-Point not the same for all Depths.—Nearly all substances expand in the act of melting, and contract in the act of solidifying. Only in a few substances, like ice, is the reverse true. Now, the fusing-point of all substances which expand in the act of fusing must be *raised by pressure*, since the expanding force of heat, in this case, must overcome not only the cohesion, but also the pressure. That this is

[1] "Cosmos," vol. iv., p. 33.

true, has been proved experimentally for many substances by Hopkins.[1] But granite and other rocks have been proved to expand in fusing; therefore the fusing-point of rocks is raised by pressure, and must be greatly raised by the inconceivable pressure to which they are subjected in the interior of the earth. For this reason, therefore, we must again go deeper to find the interior *fluid*. In the figure, m' is the point where we last found the fusing-point of 3,000°. But this is the fusing-point on the surface, or under atmospheric pressure. The pressure of fifty miles of rock would certainly greatly raise the fusing-point. Suppose it is thus raised to 3,500°: to find this we must go still deeper, to m'', perhaps seventy-five miles in depth. But the increased pressure would again raise the fusing-point; and thus, in this chase of the increasing heat after the flying fusing-point, *where* the former would overtake the latter, or whether it would overtake it at all, science is yet unable to answer.

From this line of reasoning, therefore, we conclude that the solid crust of the earth *must* be much thicker than is usually supposed, and there *may* be even no interior liquid at all.

Astronomical Reasons.—There is another and an entirely different line of reasoning which has led some of the best mathematicians and physicists to the same result. According to the *thin-crust theory*, the earth is still *substantially a liquid globe*, and therefore under the attractive influence of the sun and moon it ought to behave like a yielding liquid. Now, according to Hopkins, Thomson, and others, the earth in all its astronomical relations behaves like a rigid solid—a solid *more rigid than a solid globe of glass*—and the difference between the behavior of a liquid globe and a solid globe could easily be detected by astronomical phenomena.[2] A complete exposition of the proof would be unsuitable to an elementary work. Suffice it here to say that the force of these arguments has led many of the most advanced geologists to the conclusion that the earth, if not solid to the centre, must have a crust so thick that for all purposes of the geologist it may be regarded as *substantially solid;* that volcanoes are openings into *local* masses of liquid, not into a general interior liquid—into subterranean *fire-lakes*, not into a universal *fire-sea*—in a word, *that all the theories of igneous phenomena must be reconstructed on the basis of a solid earth.* A few geologists, however, find a compromise in the view that there exists a *semi-liquid stratum between the solid crust and a solid nucleus.*

The interior heat of the earth manifests itself at the surface in three principal forms, viz., *volcanoes*, *earthquakes*, and *gradual oscillations of the earth's crust.*

[1] *American Journal of Science and Art*, II., vol. xxxii., p. 367.

[2] Thomson has recently reaffirmed these conclusions with still greater positiveness.—*Nature*, vol. xiv., p. 426; *American Journal of Science and Art*, vol. xii., p. 336, 1876.

Section 2.—Volcanoes.

Definition.—A volcano is usually a conical mountain, with a funnel-shaped, or pit-shaped, or cup-shaped opening at the top, through which are ejected materials of various kinds, always hot and often in a fused condition. The activity of volcanoes is sometimes *constant*, as in the case of Stromboli, in Italy, from which continuous lava-streams flow ("Cosmos," vol. iv.), but more commonly *intermittent*, i. e., having periods of eruption alternating with periods of more or less complete repose. Volcanoes which have not been known to erupt during historic times are said to be *extinct*. It is impossible, however, to draw the line of distinction between active and extinct volcanoes. Vesuvius, until the great eruption which overthrew the ancient cities of Herculaneum and Pompeii, was regarded as an extinct volcano. Since that time it has been very active.

Size, Number, and Distribution.—Some volcanoes are among the loftiest mountains on our globe. *Aconcagua*, in Chili, is 23,000 feet, *Cotopaxi*, in Peru, 19,660 feet in height. These volcanic cones, however, are situated on a high plateau; their height, therefore, is not due to volcanic eruptions entirely. But *Mauna Loa*, in Hawaii, nearly 14,000 feet, and Mount Etna, 11,000 feet high, seem to be due entirely, and Mount Shasta, California, 14,440 feet, Rainier, Washington Territory, 14,444, almost entirely to this cause. The crater of Mauna Loa is two and a half miles across; that of Kilauea three miles across and 1,000 feet deep.

The *number* of known volcanoes, according to Humboldt, is 407, and of these 225 are known to have been active in the last 160 years. The actual number is, however, probably much greater. It has been estimated that, in the archipelago about Borneo alone, there are 900 volcanoes.[1] The *distribution* of volcanoes is remarkable. (*a.*) They are almost entirely confined to the *vicinity of the sea*. Two-thirds of them are found on islands in the midst of the sea, and the remainder, with the exception of a few in the interior of Asia, are near the sea-coast. Those on islands in the sea probably commenced, most of them, at the *bottom of the sea*, the islands having been formed by their agency. New islands have been suddenly formed under the eye of observers in the Mediterranean. The basin of the Pacific is the great theatre of volcanic activity, nearly seven-eighths of all known volcanoes being situated on its coasts, or on islands in its midst. (*b.*) Volcanoes are, moreover, distributed in groups (as the Hawaiian volcanoes, the Mediterranean volcanoes, the West Indian volcanoes, the volcanoes of Auvergne, etc.), or along extensive lines as if connected with a great *fissure* of the earth's crust. The most remarkable linear series of volcanoes

[1] Herschel, "Physical Geology," p. 113.

is that which belts the Pacific coast. Commencing with the Fuegian volcanoes it runs along the whole extent of the Andes, then along the Cordilleras of Mexico, the Rocky Mountains, then along the Aleutian chain of islands, Kamtchatka, the Kurile Islands, Japan Islands, Philippines, New Guinea, New Zealand, to the antarctic volcanoes Mounts Erebus and Terror, thence back by Deception Island to Fuegia again, thus completely encircling the globe. (*c.*) Volcanoes are generally formed in comparatively *recent strata.* This seems to be connected with their relation to the sea; for recent strata are abundant about the sea-coast, and the most recent are now forming in the bed of the sea. The extinct volcanoes of France and Germany are in *tertiary* regions. Possibly the retiring of the sea has extinguished them. In the oldest strata volcanic activity has apparently died out long ago.

Phenomena of an Eruption.—The phenomena of an eruption are very diverse. Sometimes there is a gradual melting of the floor of the crater, and then a rising and boiling of the liquid contents until they *quietly* overflow and form immense streams of lava, extending fifty to sixty miles. After the eruption, the melted lava again sinks and cools, and solidifies, to form the floor of the crater until another eruption. This is the case with the Hawaiian and many other volcanoes in the South Seas. In other cases, as in the Mediterranean volcanoes, and especially in many in the Indian Ocean, the eruption is fearfully *explosive.* In such cases the eruption is usually preceded by premonitory earthquakes and sounds of subterranean explosions; then the bottom of the crater is blown out with a violent explosion, throwing huge rocky fragments to great distances, often many miles; then the melted lava rises and overflows in streams running down the side of the mountain. The rise and overflow of lava are accompanied with violent explosions of gas which throw up immense quantities of ashes and cinders 6,000 and even 10,000 feet above the crater.[1] In the great eruption of Tomboro, in the island of Sumbawa near Java, in 1815, these explosions were heard in Sumatra, 970 miles distant.[2] The emission of gas usually continues after all other ejections cease. Violent storms and heavy rain accompany the eruption, and when the mountain reaches into the region of perpetual snow, as in many of the South American volcanoes, the fearful deluges produced by the sudden melting of the snows are often the most destructive phenomenon connected with the eruption.

Volcanic eruptions, therefore, may be divided into two great types, viz., the *quiet* and the *explosive.* In the one, lava-flows predominate; in the other, cinders and ashes, and steam and gas. The Hawaiian volcanoes are perhaps the best examples of the former, and the Javanese volcanoes of the latter. The Mediterranean and most other volcanoes are mixtures of these two types in varying proportions.

[1] Dana's "Manual," p. 692.

[2] Lyell, "Principles of Geology."

The quantity of materials ejected during an eruption is sometimes almost inconceivable. During the great eruption of Tomboro, already mentioned, ashes and cinders were ejected sufficient to make three Mont Blancs, or to cover the whole of Germany two feet deep.[1] The lava which streamed from Skaptar Jökull, Iceland, in 1783, has been computed to be equivalent to about twenty-one cubic miles, or to the whole quantity of water poured by the Nile into the sea in one year! These were, however, very extraordinary eruptions. In the greatest eruptions of Vesuvius the quantity of lava poured out was not more than 600,000,000 cubic feet = one square mile covered twenty-two feet deep. The volume of lava poured out by Kilauea, in 1840, is estimated by Dana as sufficient to cover one square mile of surface 800 feet deep.

Great destruction of life is often produced by volcanic eruptions. The overthrow of Herculaneum and Pompeii by ejections from Vesuvius is well known. The great eruption of Skaptar Jökull destroyed 1,300 human lives and 150,000 domestic animals. The eruption of Etna, in 1669, overwhelmed fourteen towns and villages. In the province of Tomboro, out of a population of 12,000, only twenty-six persons escaped the great eruption of 1815.

Monticules.—Eruptions occur not only from the summit-crater, but also frequently from fissures in the side of the mountain. By the immense upheaving force necessary to raise lava to the mouth of the crater of a lofty volcano, the mountain is fissured by cracks radiating from the crater in all directions. These cracks are filled with lava, which on hardening form radiating dikes which intersect the successive layers of ejections, and bind them into a stronger mass. Through these fissures the principal streams of lava often pass. During an eruption of Mauna Loa, in 1852, the immense pressure of the lava in the principal crater fissured the side of the mountain, and a fiery fountain of liquid lava, 1,000 feet wide, was projected upward through the fissure to the height of 700 feet, and continued to play for several days. Upon these fissures subordinate craters, and finally cones, are formed. These subordinate cones about the base, and upon the slopes of the principal cone, are called *monticules* or *hornitos.* There are about 600 monticules on Etna—one of them over 700 feet high (Jukes).

Materials erupted.—As we have already stated, the materials erupted are *stones*, *lava-streams*, *cinders*, *ashes*, and *gases.*

Stones.—In explosive eruptions the solid floor of the crater is often blown out with violence, and rock-fragments, sometimes of great size, are thrown to great distances.

Lava.—The term *lava* is applied to the liquid matter poured from a volcano during eruption, and also to the same when it has hardened into rock.

[1] Herschel, "Physical Geology," p. 111.

Liquid Lava.—At the time of eruption the liquidity of lava varies very much, depending partly upon the *heat*, partly on the *fusibility* of the material, and partly upon the *kind of fusion*. In the Hawaiian volcanoes the lava is a melted glass almost as thin as honey. In Kilauea this lava is often thrown into the air by the bursting of gas-bubbles, and drawn out into long threads like spun glass, which is carried by the winds, and collects in places as a soft, brownish, towy mass, called "*Pele's hair*." Completely fused lava, when cooled rapidly, forms volcanic slag or volcanic glass (*obsidian*) ; but if cooled slowly, so that the several minerals of which it is composed have time to separate and crystallize, forms *stony lava*. If it is full of gas-bubbles (*rock-froth*), and hardens in this condition, it forms *vesicular* or *scoriaceous lava*. If the quantity of gas and steam be very great, the whole liquid mass may swell into a *rock-froth*, which rises to the lip of the crater, and outpours much as porter or ale from a bottle when the cork is drawn. Or the rock-froth may be thrown violently into the air, and, hardening there, may fall again in *cindery* or *scoriaceous* masses ; or, thrown with still greater violence, the rock-froth may be broken into fine *rock-spray*, and fall as *volcanic sand and ashes*. Ashes, when consolidated by time and percolating water, or when deposited in water, form *tufa*. Thus, there are four physical conditions in which we find lava—viz., *stony*, *glassy*, *scoriaceous*, and *tufaceous*.

Again, the liquidity of lava and its character depend much on the *kind of fusion*. Daubrée has shown that all siliceous rocks and glass mixtures, in the presence of *superheated water* even in small quantities, and under pressure, will become more or less liquid, at temperatures far below that necessary to produce true fusion. At 400° Fahr., such rocks become pasty ; at 800°, completely liquid. The same change takes place at even lower temperatures if a little alkali be present. To distinguish this liquidity from that of true igneous fusion, which requires a temperature of 2,500° to 3,000°, it has been called *aqueo-igneous* or *hydrothermal fusion*. Now, very much lava at the time of eruption is in this condition. Such lava, when the pressure is suddenly removed by breaking up of the floor of the crater, and the contained water suddenly changed into steam, is blown into the finest *dust*, which is then carried to great height by the out-rushing steam, and falls again as *volcanic ashes*, which may consolidate into tufa. If the heat be not sufficient to produce complete aqueo-igneous fusion, the lava is outpoured as a kind of *rock-broth*, consisting of unfused particles in a semifused mass, which concretes into an *earthy* kind of rock. Or the material may pour out only as hot mud, which concretes into a kind of *tufa*. In fact, every variety of fusion and semifusion, depending on the degree of heat and the quantity of water, may be traced, from perfect igneous fusion through various grades of aqueo-igneous fusion, to the condition of hot mud.

It is evident that, of the two *kinds of eruption* mentioned above,

the quiet type is characterized by igneous fusion, the explosive type by aqueo-igneous fusion. In the former the heat is great, but the amount of water is small; while in the latter the heat is less, but the amount of water far greater.

The rapidity of the flow of a lava-stream depends on its fluidity. In the Hawaiian volcanoes the lava, where it issues from the crater, has been seen to flow with a velocity of fifteen miles an hour; while Vesuvian lava seldom flows at a rate of more than two or three miles an hour. Lava, like glass, passes through various grades of viscous fluidity in cooling. It gradually becomes so stiff that it may flow only a few feet per day. The froth or scum which covers the surface of a lava-stream quickly cools and hardens into a crust of vesicular lava, which may even be walked upon while the interior is still flowing beneath. In this way are often formed long *galleries*. Also the running together of the contained gas-bubbles and steam-bubbles forms huge blisters in the viscous mass, which, on hardening, form cavities often of great size.

Hardened Lava.—*Mineralogically*, lava consists essentially of feldspar, augite, and magnetite, either intimately mixed, as in glassy lava, or aggregated in more or less distinct particles or crystals, as in the stony varieties. Now, feldspar is a light-colored mineral, having a specific gravity of about 2.5, while augite and magnetite are usually very dark-colored minerals, having specific gravities of about 3.5 to 5. It is evident, therefore, that in proportion as feldspar predominates, the lava is lighter colored and of less specific gravity; and in proportion as augite and magnetite predominate, the rock is darker and heavier. Chemically, feldspar is a silicate of alumina and alkali, with excess of silica (acid silicate). The alkali may be either potash, and then it is called *potash feldspar*, or *orthoclase;* or else it is soda and lime, and then it is called *soda-lime feldspar*, or *plagioclase*. Of these two, the former is the more acid. Augite is a silicate of lime, magnesia, and iron, with excess of base (basic silicate). Therefore, lavas may be divided into two classes—*acidic lavas* and *basic lavas*. In the former, feldspar predominates, in the latter augite. Moreover, in the one the form of feldspar is orthoclase, in the other plagioclase. Further, it is seen that all lavas are *multiple silicates*, like glass: they are, therefore, true glass-mixtures. Now, the acidic lavas are a more difficultly fusible, the basic lavas a more easily fusible glass-mixture. Either of these two kinds of lava may exist in any of the conditions mentioned above—viz., as stony, glassy, vesicular, or tufaceous lava. *Trachyte* is an example of acidic lava, and *basalt* of basic lava in a stony condition. *Pumice* is a peculiar vesicular variety of feldspathic lava.

It is highly probable that the fusion and subsequent cooling of granite, or gneiss, or even of the purer varieties of mixed sandstones and clays, would make a *trachytic* lava; while the fusion and cooling of impure slates and shales and limestones would produce *basaltic* lava.

Gas, Smoke, and Flame.—The gases emitted by volcanoes are principally *steam*, *sulphurous vapor* (S and SO_2), *hydrochloric acid*, and *carbonic acid*. By far the most abundant of these is steam. In violent, explosive eruptions, which eject principally cinders and ashes, it is probable that water, mostly in the form of steam, is one of the most abundant of all the ejected materials. In quiet lava-eruptions, like those of the Hawaiian volcanoes, the quantity of steam and gases is small. It is worthy of notice, in connection with the position of volcanoes near the sea, that the gases ejected are such as might be formed from sea-water and from limestone. The so-called *smoke* and *flame* of volcanoes have no connection with combustion. The condensed vapors and the ashes suspended in the air, often in such quantities as to make midnight-darkness at high noon, form the smoke; and the red glare of the same, reflecting the light from the incandescent lava beneath, forms the apparent flame.

All volcanic ejections, except the gases, accumulate about the crater, and continue to increase with every successive eruption, forming a sort of *stratified* deposit. Sometimes the cone is made up of successive layers of lava, as in Hawaiian volcanoes; sometimes it is made up of successive layers of cinders or tufa; sometimes of alternate layers of lava and tufa. Stratified materials of this kind, however, cannot be confounded with those produced by the action of water. In the former case the stratification is not the result of the *sorting* of the materials.

Kinds of Volcanic Cones.—Volcanic cones and craters have been divided into two kinds—viz., *cones of elevation* and *cones of eruption*. A cone of elevation is formed by interior forces lifting the crust of the earth at a particular point until the latter breaks and forms a crater, through which eruptions take place. It is an *earth-bubble* which swells and breaks at the top. A cone of eruption, on the other hand, is formed by the accumulation around a crater of its own ejections. There has been much discussion among physical geologists as to whether existing volcanic cones are formed mostly by the one method or the other. We will not enter into this discussion. It seems probable, however, that most cones are principally cones of eruption, although their height and size have been increased somewhat also by elevating forces.

Mode of Formation of a Volcanic Cone.—A volcano commences—1. As a simple opening in the earth's crust, in most cases with little or no

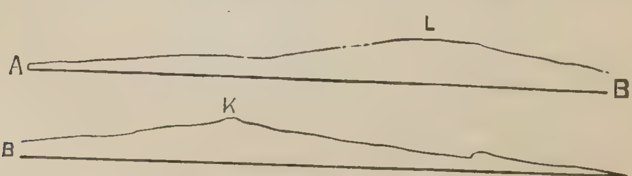


FIG. 74.—Section across Hawaii.

elevation. Through this opening or crater are ejected, from time to time, lava, cinders, ashes, etc., which accumulate immediately about the crater, and continue to increase, by successive layers, with every eruption. Ejections of pure lava, particularly if the lava is very fluid, form a cone of broad base and low inclination. This is the case with the Pacific volcanoes. Fig. 74 is a section through Hawaii, showing the slope of the pure lava-cones of Mauna Loa (L), nearly 14,000 feet high, and of Mauna Kea (K). Tufa-cones and cinder-cones (Fig. 75) take a much higher angle of slope. 2. With every eruption the powerful internal forces fissure the mountain, in lines radiating from the crater. These fissures are filled with liquid lava, which, on hardening, forms *radiating dikes*, intersecting the layers of ejections, and binding them into a more solid mass. Fig. 76 shows how these dikes, rendered more visible by erosion, intersect the strata. 3. After a time, when the mountain has grown to considerable height, the force necessary to raise liquid lava to the lip of the crater becomes so great that it breaks in preference through the fissured sides of the mountain. The secondary craters thus formed immediately commence to make accumulations around themselves, and thus form *second-*

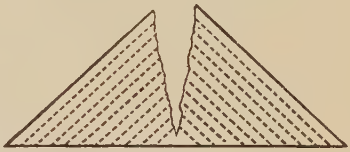


FIG. 75.—Section of Cinder-Cone.

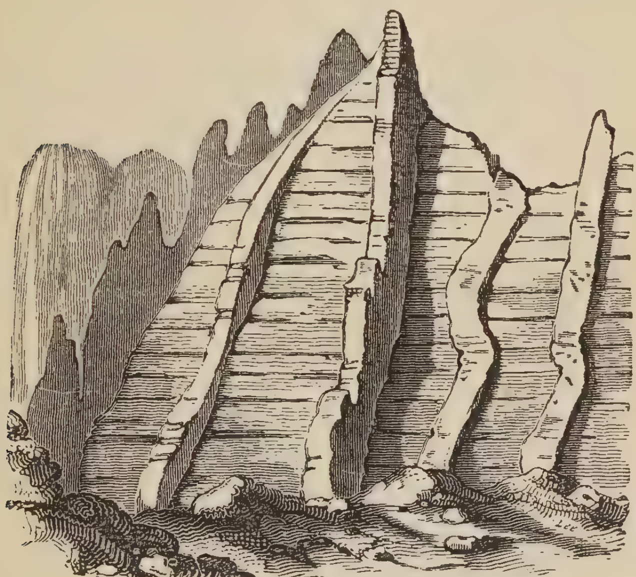


FIG. 76.—Dikes at the Base of the Serra del Solfizio, Etna.

ary cones (Fig. 77, c'), or monticules, about the base and on the sides of the primary cone. If a secondary cone becomes extinct, it is finally buried (Fig. 77, c'') in the layers of the primary cone. 4. Finally, in

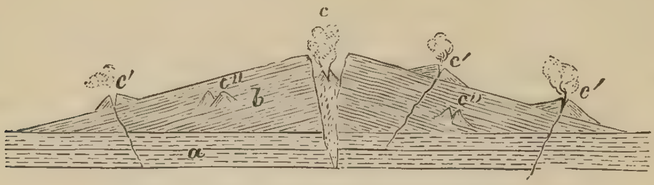


FIG. 77.—Section of Volcano, showing Monticules.

volcanoes of the explosive type, during great eruptions the whole top of the mountain is often blown off, and in volcanoes of the quieter type is melted and falls in—in either case forming an immense crater, within which, by subsequent eruptions, another smaller cone of eruption is

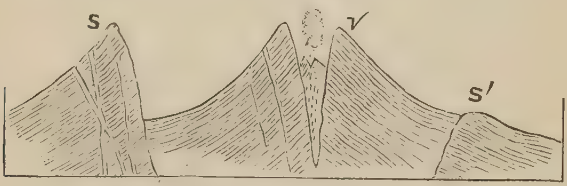


FIG. 78.—Section of Vesuvius and Mount Somma.

built up, and in this latter often a still smaller cone is again built. This *cone-within-cone* structure is well illustrated by the present condition, and still better by the history, of Vesuvius. Vesuvius is a double-peaked mountain, with a deep, semicircular valley between the peaks.

FIG. 79.—Mount Vesuvius in 1756 (after Scrope).

The present active cone of Vesuvius is encircled by a rampart, very high on one side, and called Mount Somma, but traceable to some degree all around, and having the same structure as Vesuvius itself. This rampart

is the remains of a great crater, many miles in diameter. Fig. 78 is an ideal section through Mount Somma (*S*), and Vesuvius (*V*). *S′* is the almost obliterated remains of the old crater on the other side. This is further and beautifully illustrated by the history of this mountain, which records the repeated destruction and rebuilding of these cones within cones. Fig. 79 is an outline of Vesuvius as it existed in 1756;[1] *S* is Mount Somma.

Many other volcanoes are known which have similar circular ramparts made up of layers of volcanic ejections. One of the most remarkable of these is Barren Island, in the bay of Bengal (Fig. 80). The

FIG. 80.—Section of Barren Island.

difference between this and Vesuvius is, that the circle is more complete.[2]

Comparison between a Volcanic Cone and an Exogenous Tree.—It is evident, then, that a cone of eruption grows by layers successively applied on the outside. Both in structure and growth it may, therefore, be compared to an exogenous tree: 1. As the sap ascends through the centre of the shoot and descends on the outside, forming layers of wood, one outside of the other, increasing every year the height and the diameter of the tree, so in a volcano lava ascends through the centre and pours over the outside, forming also successive layers, increasing both the diameter and the height. 2. As a cross-section of a tree shows concentric *rings* around (Fig. 81) a central *pith*, and traversed by *pith-rays*, so a cross-section of a volcano would show a central crater, with concentric layers, traversed by radiating dikes. 3. As on the pith-rays, where they emerge upon the surface, arise *buds*, which grow in a manner similar to the trunk, so on the radiating dikes are formed monticules, which grow like the principal cone. If buds die, they are covered up in the annual layers of the trunk; so, in like manner, extinct monticules are buried in the layers of the principal cone.

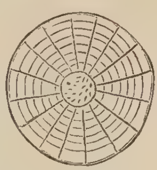


FIG. 81.

Estimate of the Age of Volcanoes.—The age of exogenous trees, as is well known, may be estimated by counting the annual rings. The age of volcanoes cannot be estimated accurately in a similar manner: 1. Because the overflows are not regularly periodical; 2. Because

[1] Scrope, *Philosophical Magazine*, vol. xiv., p. 139.

[2] Medlicot and Blandford, "Manual of Geology of India," p. 736.

in the case of lava-overflows it requires many overflows to make one complete layer; and, 3. Because it is impossible to make a complete section of the mountain. Nevertheless, Nature gives us partial sections, which reveal an almost incalculable antiquity. Thus, the Val de Bové, of Etna (a huge valley reaching from near the summit to the foot, and probably formed by an engulfment of a portion of the mountain), gives a perpendicular section into the heart of the mountain 3,000 feet deep. Throughout the whole of this section the mountain is composed entirely of layers of lava and cinders. It is almost certain, therefore, that the whole mountain to its very base, 11,000 feet, is similarly composed. That the time necessary to accumulate this immense pile, 11,000 feet high and ninety miles in circumference at the base, was almost inconceivably great, is shown by the fact that Etna had already attained very nearly its present size and shape 2,500 years ago, when it was observed by the early Greek writers. The lava-stream which stopped the Carthaginians in their march against Syracuse, 396 years before Christ, may still be seen *at the surface*, not yet covered by subsequent eruptions. And yet Etna belongs to the most recent geological epoch, for it has broken through, and is built upon, the newer tertiary strata.

Theory of Volcanoes.

In the theory of volcanoes there are two things to be accounted for, viz.: 1. The *force* necessary to raise melted lava to the crater, and even to project it with violence high into the air; 2. The *heat* necessary to fuse rocks and form lava.

Force.—The specific gravity of lava being about 2.5 to 3, it would require the pressure of one atmosphere, or fifteen pounds to the square inch, for every eleven or twelve feet of vertical elevation of the liquid mass. The following table gives the pressure in atmospheres for four well-known volcanoes, assuming the point of hydrostatic equilibrium to be at the sea level:

NAME.	Height.	Pressure in Atmospheres.
Vesuvius	3,900 feet	325
Etna	11,000 "	920
Mauna Loa	13,800 "	1.150
Cotopaxi	19,660 "	1.638

The lava is often, however, in a frothy or vesicular condition. In such cases the pressure necessary to produce overflow would be much less. But, on the other hand, the force in most cases is not only sufficient to lift lava to the top of the crater, but to project it thousands of feet in the air. A rock-mass of over 2,700 cubic feet was projected from the crater of Cotopaxi to a distance of nine miles (Lyell). The *agent* of

this prodigious force is evidently gas and vapors, especially steam. The great quantity of steam issuing from all volcanoes, but especially from those of the explosive type, is sufficient proof. Thus far theorists generally agree, but from this point opinions diverge into the most opposite directions.

The Heat.—There are many and diverse opinions as to the source of the heat associated with volcanic eruptions. Two prominent views, however, may be said to divide geologists. According to the *one*, the heat is the remains of the *primal* heat of the once universally incandescent earth ; according to the other, the heat is produced by *chemical* or *mechanical* action. According to the former, the heat is general, and only the access of water is local ; according to the latter, both the heat and the access of water are local. According to the former, volcanoes are openings through the comparatively thin crust, revealing the universal interior fluid ; according to the latter, they are openings into isolated interior lakes of molten matter. The former may be called the "interior fluidity" theory ; the latter divides into two branches, which may be called respectively the "chemical" and the "mechanical" theory. In all, access of water to the hot interior furnishes the force.

Internal Fluidity Theory.—This theory supposes that the earth, from its original incandescent condition, slowly cooled and formed a surface-crust ; that this surface-crust, though ever thickening by additions to its interior surface, is still comparatively very thin, and beneath it is still the universal incandescent liquid ; that by movements of the surface the solid crust is fissured, and water from the sea or from other sources finds its way to the incandescent liquid mass, and develops elastic force sufficient to produce eruption.

By this view the focus of volcanoes is situated at the lower limit of the solid crust. The theory seems clear and simple enough, but when closely examined there are many difficulties in the way of its acceptance.

Objections.—The objections to this view are : 1. That the crust, as already shown, must be far thicker than this theory requires, probably hundreds of miles thick, if, indeed, there be any general liquid interior at all ; but volcanoes are evidently very superficial phenomena. Under the pressure of this difficulty these theorists have been driven to the acknowledgment of *local thinnings* of the solid crust in the region of volcanoes.

2. Pressure on a general interior liquid from any cause at any place would, by the law of hydrostatics, be transmitted equally to every part of the crust, which would, therefore, yield at the weakest point, wherever that may be, even though it be on the opposite side of the globe ; but the force of volcanic eruption is evidently just beneath the volcano.

3. Volcanoes belonging to the same group, and therefore near to-

gether, often erupt independently, as if each had its own reservoir of liquid matter. The pressure of these two objections has driven many to the admission of a sort of *honey-combed remains* of the interior liquid inclosed in the solid crust, and now isolated both from the interior liquid and from each other.

4. There is a limit to the descent of water into the interior of the earth; gravity urges it downward, but the interior heat drives it back. The limit, therefore, will be where these two balance each other, i. e., where the elastic force of steam is equal to the superincumbent column of water. We will call this point the *limit of volcanic waters*. It is evident that when water was first condensed on the cooling earth, this limit was at the surface: water could not penetrate at all. As the earth cooled, this limit became deeper and deeper; and, if the earth became perfectly cool to the centre, there is little doubt that the whole of the water on the earth would be absorbed. This is perhaps the case with the moon now.

Now, it seems probable that at the limit of volcanic water the interior heat of the earth, increasing at the rate of 1° for every fifty feet, would be far short of the temperature necessary for igneous fusion of rocks. Again, the elastic force necessary to sustain the superincumbent *water* would by no means be sufficient to break up the crust of the earth, or raise melted *lava* to the surface.

But we will not pursue this subject, as it is too complex to be yet solved by science. We rely, therefore, on the first three objections.

Chemical Theory.—Whether or not the earth consist of solid crust covering an interior liquid, it almost certainly consists of an *oxidized crust* covering an *unoxidized interior*. Now, the oxidizing agents are water and air, and therefore the limit of the oxidized crust is the limit of volcanic water. Therefore, the oxidizing agent and the unoxidized material are in close proximity, and the former ever encroaching on the latter, and therefore liable at any moment to set up chemical action, the intensity of which would vary with the nature of the material. If the action be intense, heat may be formed sufficient to fuse the rocks and to develop elastic force necessary to produce eruption.

In this general form, the chemical theory seems plausible, but many have attempted to give it more definiteness, and to explain the special forms of oxidization which cause volcanoes. The most celebrated of these definite forms is that of Sir Humphry Davy, who attributed it to the contact of water with metallic potassium, sodium, calcium and magnesium, in the interior of the earth. In such definite forms the theory seems far too hypothetical.

Recent Theories.—1. *Aqueo-igneous Theory.*—Accumulation of sediment on sea-bottoms would necessarily produce corresponding rise of isogeotherms, and thus the interior heat of the earth would invade

the sediments with their contained waters. The lower portion of sediments 10,000 feet thick would be raised to a temperature of about 260°, and of 40,000 feet thick (sediments of this thickness and more are known) to that of 860°. This temperature, or even a less temperature if alkali be present, would be sufficient in the presence of the contained water of the sediments to produce complete aqueo-igneous fusion, and probably to develop elastic force sufficient to produce eruption. This view was first brought forward by John Herschel. Observe that this temperature and the corresponding force would be gradually developed as the accumulation progressed, until sufficient to produce these effects. Observe, again, that in this case the water does not seek the heat by *descending*, but the heat seeks the already imprisoned water by *ascending*.

It seems very probable that cases of eruption of hot mud and of aqueo-igneously fused lavas may be accounted for in this way, but the temperature would not be sufficient to account for true igneous fusion.

Some geologists go much further, and, supposing that the whole surface of the earth consists of sedimentary rocks of great thickness, imagine that between the solid surface and a solid nucleus there exists a continuous layer of aqueo-igneously fused matter which is the seat of igneous activity.

2. *Mechanical Theory.*—As we shall explain hereafter (p. 252), there is much reason to believe that the interior of the earth is contracting more rapidly than the exterior, and that the exterior is thus necessarily thrust upon itself by irresistible horizontal pressure. According to Mr. Mallet, the crushing of the rocky crust in places under this pressure develops heat sufficient to fuse the rocks, and to produce eruption. But it is at least doubtful whether the heat thus generated would alone be sufficient for this purpose.

3. *Issuing of Super-heated Gases.*—Very recently Rev. O. Fisher has advanced a view which deserves attention. He thinks volcanoes are vents through which issue from the earth's interior super-heated steam and gases, melting the rocks in their course and ejecting them by their pressure. According to this view, the water is not derived from the surface, but is original and constituent. This view is independent of the condition of the earth's interior, whether solid or liquid; for a temperature which would permit solidity at great depths would produce fusion under less pressure near the surface.[1] The sun may be regarded as a globe in an earlier and more active stage of vulcanism. From its interior gases are seen to issue in great quantity, and almost constantly.

The complete development of these later theories cannot be undertaken in this part of our treatise. We will take the subject up again under the head of Mountain Formation (p. 250).

[1] Cambridge Philosophical Society, 1875.

Subordinate Volcanic Phenomena.

These are *hot springs*, *carbonated springs*, *solfataras*, *fumaroles*, *mud-volcanoes*, and *geysers*. They are all *secondary* phenomena, i. e., formed by the percolation of meteoric water through hot volcanic ejections. Or perhaps in some cases the heat may be produced by slow rock-crushing by horizontal pressure, as explained above.

General Explanation.—Thick masses of lava outpoured from volcanoes remain hot in their interior for an incalculable time. Water percolating through these acquires their heat, and comes up again as hot springs; or, if it contains carbonic acid, as carbonated springs; or, if it contains sulphurous acid and sulphureted hydrogen, as solfataras. If condensable vapors issue in abundance so as to make an appearance of smoke, they are called fumaroles. If the hot water brings up with it mud which accumulates about the vent, then it is a mud-spring or a mud-volcano. If the heat is very great, so that violent eruption of water takes place periodically, then it becomes a geyser. This is the only one which need detain us.

Geysers.

A geyser may be defined as a *periodically eruptive spring*. They are found only in Iceland, in the Yellowstone Park, United States, and in New Zealand. The so-called geysers of California are rather fumaroles. Those of Iceland have been long studied; we will, therefore, describe these first.

Iceland is an elevated plateau about two thousand feet high, with a narrow marginal habitable region sloping gently to the sea. The elevated plateau is the seat of every species of volcanic action, viz., lava-eruptions, solfataras, mud-volcanoes, hot springs, and geysers. These last exist in great numbers; more than one hundred are found in a circle of two miles diameter. One of these, the *Great Geyser*, has long attracted attention.

Description.—The Great Geyser is a basin or pool fifty-six feet in diameter, on the top of a mound thirty feet high. From the bottom of the basin descends a funnel-shaped pipe eighteen feet in diameter at top, and seventy-eight feet deep. Both the basin and the tube are lined with silica, evidently deposited from the water. The natural inference is, that the mound is built up by deposit from the water, in somewhat the same manner as a volcanic cone is built up by its own ejections. In the intervals between the eruptions the basin is filled to the brim with perfectly transparent water, having a temperature of about 170° to 180°.

Phenomena of an Eruption.—1. Immediately preceding the eruption sounds like cannonading are heard beneath, and bubbles rise and break on the surface of the water. 2. A bulging of the surface is then

seen, and the water overflows the basin. 3. Immediately thereafter the whole of the water in the tube and basin is shot upward one hundred feet high, forming a fountain of dazzling splendor. 4. The eruption of water is immediately followed by the escape of steam with a roaring

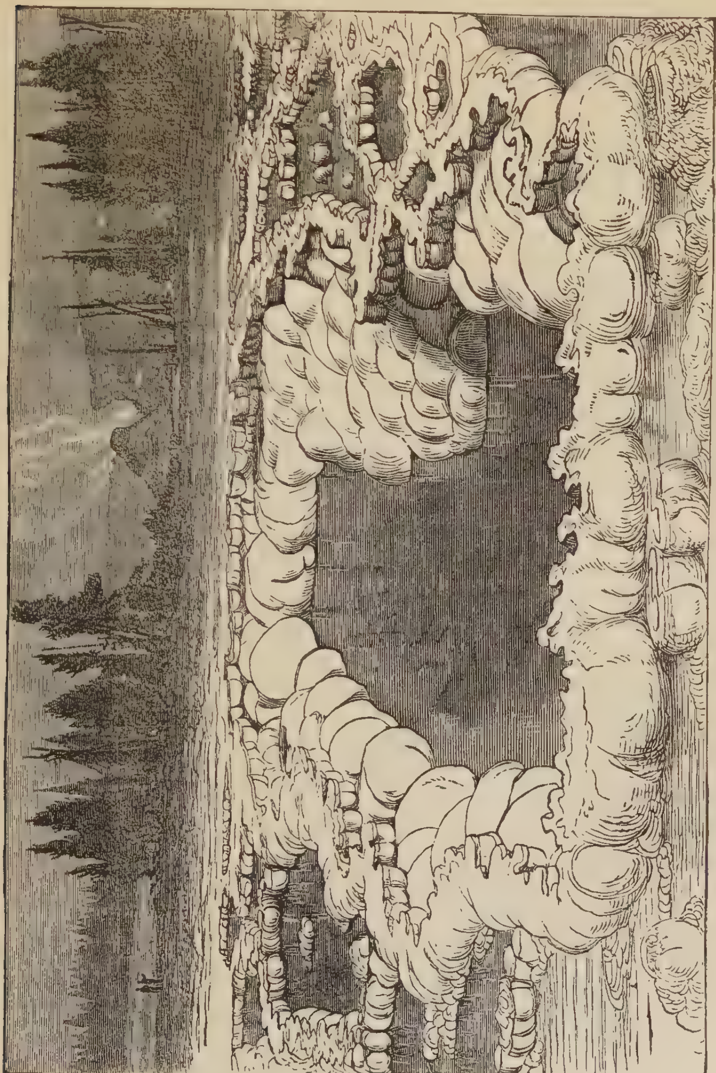


FIG. 82.—Geyser near the Giant, showing the Ornamental Character of the Border (after Hayden).

noise. These last two phenomena are repeated several times, so that the fountain continues to play for several minutes, until the water is sufficiently cooled, and then all is again quiet until another eruption.

The eruptions occur tolerably regularly every ninety minutes, and last six or seven minutes. Throwing large stones into the tube has the effect of bringing on the eruption more quickly.

Yellowstone Geysers.—In magnificence of geyser displays, however, Iceland is far surpassed by the geyser basin of Firehole River. This wonderful geyser region is situated in the northwest corner of Wyoming, on an elevated volcanic plateau near the head-waters of the Madison River, a tributary of the Missouri, and of the Snake River, a tributary of the Columbia. The basin is only about three miles wide. About it are abundant evidences of prodigious volcanic activity in former times, and, although primary volcanic activity has ceased, secondary volcanic phenomena are developed on a stupendous scale and of every kind, viz.: hot springs, carbonated springs, fumaroles, mud-volcanoes, and geysers. In this vicinity there are more than 10,000 vents of all kinds. In some places, as on Gardiner's River, the hot springs are mostly lime-depositing (p. 71); in others, as on Firehole River, they are geysers depositing silica.

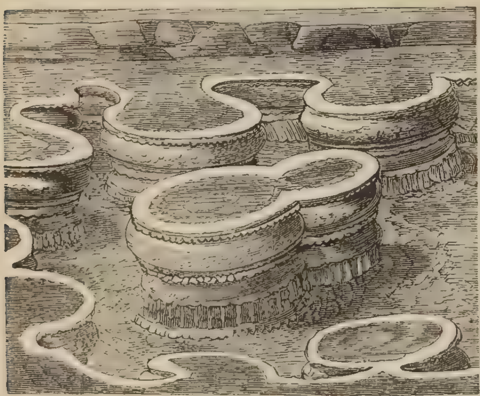


Fig. 83.—(After Hayden.)

In the upper geyser basin the valley is covered with a snowy de-

Fig. 84.—The Turban (after Hayden).

posit from the hot geyser-waters. The surface of the mound-like, chimney-like, and hive-like elevations, immediately surrounding the

vents, is, in some cases, ornamented in the most exquisite manner by deposits of the same, in the form of scalloped embroidery set with pearly tubercles; in others, the siliceous deposits take the most fan-

FIG. 85.—Giant Geyser (after Hayden).

tastic forms (Figs. 82, 83, 84). In some places the silica is deposited in large quantities, three or four inches deep, in a gelatinous condition like starch-paste. Trunks and branches of trees immersed in these waters are speedily petrified.

We can only mention a few of the grandest of these geysers :

1. The "Grand Geyser," according to Hayden, throws up a column of water six feet in diameter to the height of 200 feet, while the steam ascends 1,000 feet or more. The eruption is repeated every thirty-two hours, and lasts twenty minutes. In a state of quiescence the temperature of the water at the surface is about 150°.

FIG. 86.—Bee-Hive Geyser (from a Drawing by Holmes).

2. The "Giantess" throws up a large column twenty feet in diameter to a height of sixty feet, and through this great mass it shoots up five or six lesser jets to a height of 250 feet. It erupts about once in every eleven hours, and plays twenty minutes.

3. The "Giant" (Fig. 85) throws a column five feet in diameter 140 feet high, and plays continuously for three hours.

4. The "Bee-Hive" (Fig. 86), so called from the shape of its mound, shoots up a splendid column two or three feet in diameter to the height by measurement of 219 feet, and plays fifteen minutes.

5. "Old Faithful," so called from the frequency and regularity of its eruptions, throws up a column six feet in diameter to the height of 100 to 150 feet regularly every hour, and plays each time fifteen minutes.

Fig. 87.—Forms of Geyser-Craters (after Hayden).

Theories of Geyser-Eruption.—The water of geysers is not volcanic water, but simple spring-water. A geyser is not, therefore, a volcano ejecting water, but a true spring. There has been much speculation concerning the cause of their truly wonderful eruptions.

Mackenzie's Theory.—According to Mackenzie, the eruptions of the Great Geyser may be accounted for by supposing its pipe connected by a narrow conduit with the lower part of a subterranean cave, whose walls are heated by the near vicinity of volcanic fires. Fig. 88 represents a section through the basin, tube and supposed cave. Now, if meteoric water should run into the cave through fissures more rapidly than it can evaporate, it would accumulate until it rose above, and therefore closed, the opening at *a*. The steam, now having no outlet, would condense in the chamber *b* until its pressure raised the water into the pipe, and caused it to overflow the basin. The pressure still continuing, all the water would be driven out of the cave, and partly up the pipe. Now, the pressure which sustained the whole column *a d*

would not only sustain, but eject with violence, the column *c d*. The steam would escape, the ejected water would cool, and a period of quiescence would follow. If there were but one geyser in Iceland, this would be rightly considered a very ingenious and probable hypothesis, for without doubt we may conceive of a cave and conduit so constructed as to account for the phenomena. But there are many eruptive springs in Iceland, and it is inconceivable that all of them should have caves and conduits so peculiarly constructed. This theory is therefore entirely untenable.

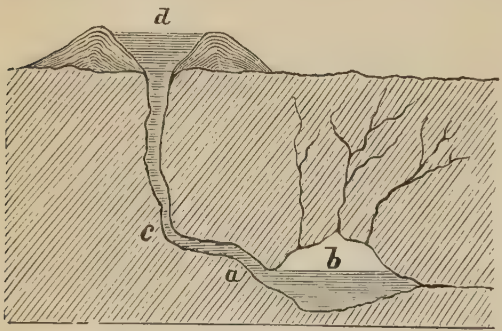


FIG. 88.—Mackenzie's Theory of Eruption.

Bunsen's Investigations.—The investigations of Bunsen and his theory of the eruption and the formation of geysers are among the most beautiful illustrations of scientific induction which we have in geology. We therefore give it, perhaps, more fully than its strict geological importance warrants.

Bunsen examined all the phenomena of hot springs in Iceland. 1. He ascertained that geyser-water is meteoric water, containing the soluble matters of the igneous rocks in the vicinity. He formed identical water by digesting Iceland rocks in hot rain-water. 2. He ascertained that there are two kinds of hot springs in Iceland, viz., *acid springs* and *alkaline-carbonate springs*, and that only alkaline-carbonate springs contain any silica in solution. The reason is obvious: alkaline waters, especially if hot, are the natural solvents of silica. 3. He ascertained that *only the silicated springs form geysers.* Here is one important step taken—one condition of geyser-formation discovered. Deposit of silica is necessary to the existence of geysers. The tube of a geyser is not an accidental conduit, but is built up by its own deposit. 4. Of silicated springs, *only those with long tubes erupt*—another condition. 5. Contrary to previous opinion, the silica in solution does not deposit on cooling, but only by drying. This would make the building-up of a geyser-tube an inconceivably slow process, and the time proportionally long. This, however, is not true, for the Yellowstone geyser-waters, which deposit abundantly by *cooling*, evidently because they contain much more silica than those of Iceland. 6. The temperature of the water in the basin was found to be usually 170° to 180°, and that in the tube to increase rapidly, though not regularly, with depth. Moreover, the temperature, both at the surface and at

all depths, increased regularly as the time of eruption approached. Just before the eruption it was, at the depth of about forty-five feet, very near the boiling-point *for that depth.*

Theory of Geyser-Eruption—Principles.—1. It is well known that the boiling-point of water rises as the pressure increases. This is shown in the adjoining table. 2. It follows from the above that if water be under strong pressure, and at high temperature, though below its boiling-point for that pressure, and the pressure be diminished sufficiently, it will immediately flash into steam. 3. Water heated beneath, if the circulation be unimpeded, is *very nearly* the same temperature throughout. That it is never the same temperature precisely is shown by the circulation itself, which is caused by difference of temperature, producing difference in density. The phenomenon of simmering is also a well-known evidence of this difference of temperature, since it is produced by the collapse of steam-bubbles rising into the cooler water above. 4. But if the circulation be *impeded*, as when the water is contained in long, narrow, irregular tubes, and heated with great rapidity, the temperature may be greater below than above to any extent, and the boiling-point may be reached in the lower part of the tube, while it is far from this point in the upper part.

Pressure in Atmospheres.	Boiling-Point.
1 Atmos.	212°
2 "	250°
3 "	275°
4 "	293°

Application to Geysers.—We will suppose a geyser to have a simple but irregular tube, without a cave, heated below by volcanic fires, or by still hot volcanic ejections. Now, we have already seen that the temperature of the water in the tube increases rapidly with the depth, but is, at every depth to which observation extends, short of the boiling-point for that depth. Let absciss *a d* (Fig. 89) represent depth in the tube, and also pressures; and the corresponding temperature be measured on the ordinate *a n*. If, then, *a b*, *b c*, *c d*, represent equal depths of thirty-three or more feet, which is equal to one atmospheric pressure, the curve *e f* passing through 212°, 250°, 275°, and 293°, at the horizontal lines, representing one atmosphere, two atmospheres, three atmospheres, etc., would correctly represent the increasing boiling-points as we pass downward. We shall call this line, *e f*, *the curve of boiling-point.* The line *a g* commencing at the surface at 180°,

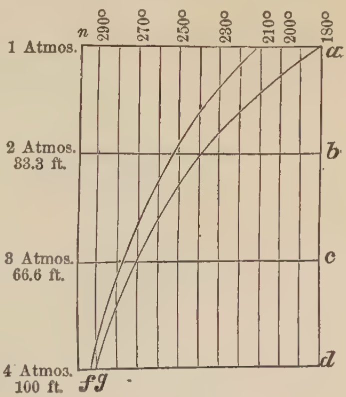


Fig. 89.

and gradually approaching the boiling-point line, but everywhere within it, would represent the actual temperature in a state of quiescence. Now, Bunsen found that, as the time of eruption approached, the temperature at every depth approached the boiling-point for that depth, i. e., the line *a g* moved toward the line *e f*. There is no doubt, therefore, that, at the moment of eruption, at some point below the reach of observation, the line *a g* actually touches the line *e f*—the boiling-point for that depth is actually reached. As soon as this occurs, a quantity of water in the lower portion of the tube, or perhaps even in the subterranean channels which lead to the tube, would be changed into steam, and the expanding steam would lift the whole column of water in the tube, and cause the water in the basin to *bulge and overflow*. As soon as the water overflowed, the pressure would be diminished in every part of the tube, and consequently a large quantity of water before very near the boiling-point would flash into steam and instantly eject the whole of the water in the pipe ; and the steam itself would rush out immediately afterward. The premonitory cannonading beneath is evidently produced by the collapse of large steam-bubbles rising through the cooler water of the upper part of the tube ; in other words, it is *simmering on a huge scale*. An eruption is more quickly brought on by throwing stones into the throat of the geyser, because the circulation is thus more effectually impeded.

The theory given above is substantially that of Bunsen for the eruption of the Great Geyser, but modified to make it applicable to all geysers. In the Great Geyser, as already stated, Bunsen found a point, forty-five feet deep, where the temperature was nearer the boiling-point than at any *within* reach of observation, though doubtless *beyond* the reach of observation the temperature again approached and *touched the boiling-point*. This point, forty-five feet deep, plays an important part in Bunsen's theory. To illustrate : if *e f* (Fig. 90) represent again the curve of boiling-point, then the curve of actual temperature in the Great Geyser tube would be the irregular line *a g h*. At the moment of eruption, this line touched boiling-point at some depth, *h*, beyond the reach of observation. Then followed the lifting of the column, the overflow of the basin, the relief of pressure by which the point *g* was brought to the boiling-point, the instantaneous formation of steam at *g*, and

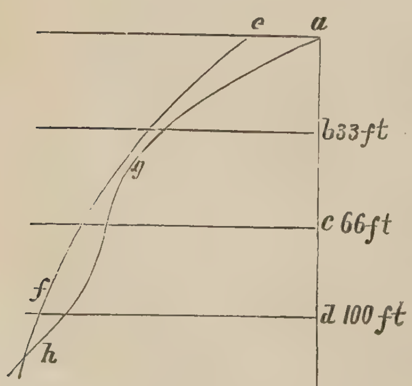


FIG. 90.

the phenomena of an eruption. But it is extremely unlikely that this condition should exist in all geysers; neither is it at all necessary in order to explain the phenomenon of an eruption.

To prove beyond question the truth of his theory, Bunsen constructed an artificial geyser. The apparatus (Fig. 91) consisted of a tube of tinned sheet-iron about ten feet long, expanded into a dish above for catching the erupted water. It may or may not be expanded below for the convenience of heating. It was heated, also, a little below the middle, by an encircling charcoal chauffer, to represent the point of nearest approach to the boiling-point in the geyser-tube. When this apparatus was heated at the two points, as shown in the figure, the phenomena of geyser-eruption were completely reproduced; first, the violent explosive simmering, then the overflow, then the eruption, and then the state of quiescence. In Bunsen's experiment, the eruptions occurred about every thirty minutes.

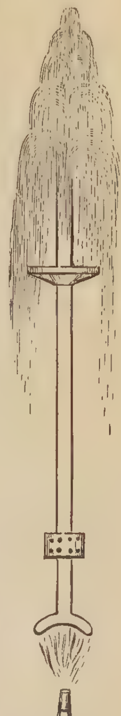


Fig. 91.—Artificial Geyser.

Bunsen's Theory of Geyser-Formation.—According to Bunsen, a geyser does not find a cave, or even a perpendicular tube, ready made, but, like volcanoes, makes its own tube. Fig. 92 is an ideal section of a geyser-mound, showing the manner in which, according to this view, it is formed. The irregular line, *b a c*, is the original surface, and *a* the position of a hot spring. If the spring be not alkaline, it will remain an ordinary hot spring; but, if it be alkaline, it will hold silica in solution, and the silica will be deposited about the spring. Thus the mound and tube are gradually built up. For a long time the spring will not be eruptive, for the circulation will maintain a nearly equal temperature in every part of the tube—it may be a *boiling*, but not an eruptive spring. But, as the tube becomes longer, and the circulation more and more impeded, the difference of temperature between the upper and lower parts of the tube becomes greater and greater, until, finally, the boiling-point is reached below, while the water above is comparatively cool. Then the eruption commences. Finally, from the gradual failure of the subterranean heat, or from the increasing length of the tube repressing the formation of

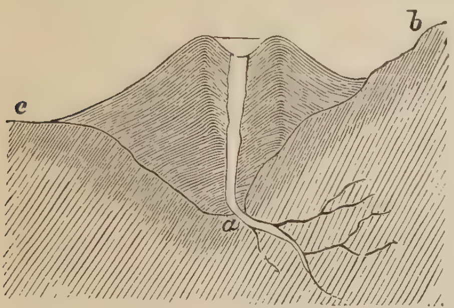


Fig. 92.—Ideal Section of a Geyser-Tube, according to Bunsen.

steam, the eruptions gradually cease. Bunsen found geysers in every stage of development—some playful springs without tubes; some with short tubes, not yet eruptive; some with long tubes, violently eruptive; some becoming old and indisposed to erupt unless angered by throwing stones down the throat.

It is evident, however, that Bunsen's theory of geyser-eruption is independent of his theory of geyser-formation. A tube or fissure of any kind, and formed in any way, if long enough, would give rise to the same phenomena. The Yellowstone geysers have mounds or chimney-like cones, but it is by no means certain that the whole length of their eruptive tubes has been built up by siliceous deposit. Bunsen's theory of eruption none the less, however, applies to these also. The more chimney-like form of the craters in the case of the Yellowstone geysers is probably due to the greater abundance of silica in solution.

Section 3.—Earthquakes.

Only very recently, and mainly through the labors of Mr. Mallet,[1] of England, our knowledge on the subject of earthquakes has commenced to take on scientific form. This slowness of advance has arisen not from any want of materials, but from the great complexity of the phenomena, their origin deep within the bowels of the earth and therefore removed from observation, and, more than all, from the surprise and alarm usually produced unfitting the mind for scientific observation. For these reasons, until fifteen or twenty years ago, the state of knowledge on this subject was much the same as it was 2,000 years ago. And yet now, we think, our knowledge of earthquakes is even more advanced than that of volcanoes.

Frequency.—Mallet, in his earthquake catalogue, has collected the records of 6,830 earthquakes as occurring in 3,456 years previous to 1850; but, of that number, 3,240, or nearly one-half, occurred in the last fifty years; not because earthquakes were more numerous, but because the records were more perfect. If the records had been equally complete throughout the whole time, the number would have been over 200,000. Taking the last four years of his record, the number was about two a week. According to the more complete catalogue of Alexis Perrey,[2] from 1843 to 1872, inclusive, there were 17,249, or 575 per annum. It seems probable, therefore, that, considering the fact that even now the larger number of earthquakes are not recorded, occurring in mid-ocean or in uncivilized regions, the earth is *constantly quaking* in some portion of its surface.

Connection with other Forms of Igneous Agency.—The close connection of earthquakes with volcanoes is undoubted: 1. Volcanic eruptions,

[1] "Transactions of British Association, 1850–1858;" also, "Principles of Seismology."

[2] *American Journal of Science*, vol. xi., p. 233, 1876.

especially those of the explosive type, are always preceded and accompanied by earthquakes. 2. Earthquake-shocks which have continued to trouble a particular region for a long time, often suddenly cease when an outburst takes place in a neighboring volcano, showing that the latter are safety-vents for the interior forces which produce earthquakes. Also, the sudden cessation of accustomed volcanic activity will often bring on earthquakes. Thus, when the wreath of smoke disappears from Cotopaxi, the inhabitants of Quito expect earthquakes. During the great Calabrian earthquake of 1783, Stromboli, for the first time in the memory of man, ceased erupting. The great earthquake which destroyed Riobamba in 1797, and in which 40,000 persons perished, took place immediately after the stopping of activity in a neighboring volcano. The earthquake-shocks which destroyed Carácas in 1812 ceased as soon as St. Vincent, 500 miles distant, commenced erupting. 3. Examination of Prof. Mallet's earthquake-map shows that the distribution of earthquake-centres is much the same as that of volcanoes already given (page 81). It may be regarded as almost certain, therefore, that the forces which generate earthquakes are closely allied, if not identical, with those which produce volcanic eruptions.

Again, the connection of earthquakes with bodily movements of great areas of the earth's crust, by elevation or depression, is equally close. In 1835, after a great earthquake, which shook the coast of South America over an area of 600,000 square miles, the whole coast-line of Chili and Patagonia was found elevated from two to ten feet above sea-level. Again, in 1822, after a similar earthquake in the same region, the coast-line was found elevated from two to seven feet. Now, in this very region, old beach-marks, 100 feet to 1,300 feet above the sea-level, and extending 1,200 miles along the coast on each side of the southern end of this continent, plainly show that, in very recent geological times, the whole southern end of South America has been bodily raised out of the sea to that extent. It is impossible to doubt that the force which produced this continental elevation was also the cause of the accompanying earthquakes. Again, in 1819, after a severe earthquake, which shook the whole region about the mouth of the Indus, a large tract of land of 2,000 square miles was sunk and became a salt lagoon; while another area, fifty miles long and ten to sixteen miles wide, was elevated ten feet. In commemoration of this wonderful event, the raised portion was called Ullah Bund, or the Mound of God. Again, in 1811, a severe earthquake shook the valley of the Mississippi. In the region about the mouth of the Ohio, where it was severest, large tracts of land were sunk bodily several feet below their former level, and have been covered with water ever since. It is now called the "*Sunk Country.*" In the two cases last mentioned there was evidently formed a *fault* or *dislocation*, i. e., there was a fissure in

the earth's crust, and one side dropped down lower than the other. Such fissures and faults are found intersecting the earth in all directions. We see them, in these cases, formed under our eyes, and in connection with earthquakes.

Ultimate Cause of Earthquakes.—The connection of earthquakes with the two other forms of igneous agency suggests each a possible cause. Preceding and accompanying volcanic eruptions, especially of the explosive type, occur subterranean explosions, which are often heard hundreds of miles. Such eruptions are also accompanied with escape of immense quantities of steam and gas. These facts, together with the association of earthquakes with volcanoes, have suggested the idea that the sudden formation or the sudden collapse of vapor is the cause of earthquakes. According to this view, an earthquake is, on a grand scale, a phenomenon similar to the *jar* produced by the explosion of a keg of gunpowder buried in the earth.

But the association of earthquakes with bodily movements of large areas of the earth's crust suggests another and a far more probable cause. The earth's crust, as is well known, is in gradual movement by elevation or depression almost everywhere. These movements, as we shall show hereafter, are probably due to the greater interior contraction of the earth thrusting the crust upon itself, by horizontal pressure. If the yielding is constant like the force, the movement will be gradual; but if the crust resists, and the force still accumulates, the yielding must take place suddenly by *fissure* or *crushing*. The walls of such fissures rarely remain in position, but are usually *slipped*, sometimes many thousand feet. The sudden formation or the sudden slipping of a fissure would certainly produce a concussion or *jar*, which, propagating itself, would finally reach the surface and spread outward from the point of first emergence. Furthermore, when we remember that these fissures often break through thousands of feet and even miles in thickness of solid rock, we easily perceive that the resulting concussion would be fully adequate to produce all the dreadful effects of earthquakes.

Proximate Cause.—But whatever be our view of the ultimate cause of earthquakes, there can be no doubt that the *proximate* or immediate cause of the observed effects is the arrival of an earth-jar—the emergence, on the earth-surface, of a succession of elastic earth-waves, produced by a violent concussion of some kind in the interior. Evidently, therefore, the discussion of earthquake phenomena is nothing more than the discussion of the laws of propagation and the effects of elastic waves occurring under peculiar and very complex conditions. It is impossible to understand the subject without some preliminary knowledge of the nature and properties of waves. For the sake of greater clearness we will state some principles which we will make use of in this discussion.

Waves—their Kinds and Properties.—Waves may be classified in several ways, according to the point of view from which we regard them. Regarding only the force of propagation, they are divided into waves of gravity and waves of elasticity. Regarding the direction of oscillation, they are divided into waves of transverse and waves of longitudinal oscillation; regarding the form, into circular and spherical waves.

$$\text{Waves}\begin{cases}\text{of elasticity} \longrightarrow \text{longitudinal oscillation} \longleftarrow \text{spherical.} \\ \text{of gravity} \longrightarrow \text{transverse oscillation} \longleftarrow \text{circular.}\end{cases}$$

A wave of elasticity may have either longitudinal or transverse oscillation, as shown in the diagram, but those of which we shall speak will be principally the former. Waves of gravity are always of transverse vibration. Spherical waves are of longitudinal vibration, and circular waves are transverse.

If a stone be thrown into still water a series of waves run in every direction from the point of disturbance, becoming lower and lower as the distance increases, until they become insensible. These are *circular* waves of *transverse* oscillation propagated by *gravity* alone. The direction of propagation is along the surface of the water in direction of the radius of the circle; the direction of oscillation is up and down, or transverse to the direction of propagation.[1] Water-waves are, therefore, transverse waves of gravity, and, if propagated from a central point, are circular. They move with uniform velocity; their height decreases as they pass outward. If, on the other hand, an impulse like an explosion originate *in the interior* of a medium, as, for example, in the air or in the interior of the earth, the impulse acting in every direction compresses a spherical shell of matter all around itself, while the point of impulse itself passes into a state of rarefaction; this compressed shell in expanding by its *elastic force* compresses the next outer shell of matter, itself becoming rarefied in the act, and this last in its turn propagates the impulse to the next, and so on. Thus, if only a single wave were formed, there would run outward from the focal point an ever-widening spherical shell of compressed matter, followed closely by a similar shell of rarefied matter. But in every case of impulse or concussion there is always a series of such alternate compressed and rarefied shells following one another. The alternate compression and rarefaction causes each particle in succession to move forth and back. This oscillatory motion is in the direction of propagation of the wave, and therefore *longitudinal.* All waves propagated from a point within a medium, such as *sound-waves*, are elastic spherical waves of longitudinal oscillation.

Definition of Terms.—In transverse waves, such as water-waves, the

[1] The actual path described by a particle in oscillating is a small ellipse, whose plane is vertical.

distance from wave-crest to wave-crest, or from wave-trough to wave-trough, is called the *wave-length,* and the perpendicular distance from trough to crest is called the wave-height. Similar terms are used in speaking of waves of longitudinal vibrations. The sense in which they are used and their propriety are shown in the accompanying figure (Fig. 93). Let the bar *A B* represent a prism cut from a vibrating sphere in the direction of the radius, i. e., the direction of propagation of the wave, and let the dark and light portions represent condensation and rarefaction. Now, on the line *a b*, representing the natural state of the

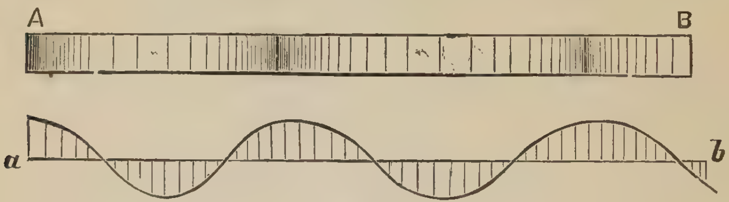


Fig. 93.

bar, draw ordinates *above*, to represent the degrees of compression, and *below*, to represent degrees of rarefaction; then the undulating line will correctly represent the state of the bar during the transmission of elastic longitudinal waves. Thus longitudinal waves may be represented in the same way as transverse waves. The most compressed portions are called crests, and the most rarefied troughs; from crest to crest is the length, and the amount of oscillation of the particles back and forth in compression and rarefaction is the height of the wave. We shall be compelled to use these terms in speaking of earthquake-waves.

Thus, then, there are two very distinct kinds of waves, both of which are common—viz., *circular waves of gravity*, of which water-waves are the type, and *spherical elastic waves*, of which sound-waves are the type. We will have much to do with both of these in the explanation of earthquake phenomena.

The *velocity* of *water-waves* depends wholly on the *wave-length*, and not at all on the *wave-height.* Therefore, water-waves run with uniform motion, since, although their height diminishes, their length remains the same. But there is one important exception to this law, and one which peculiarly concerns us in this discussion—viz., when the length of waves is great in proportion to the depth of the water, then they *drag bottom*, and their velocity is a function of the *depth of the water* as well as of the length of the wave.

The velocity of *elastic* waves, on the other hand, is not affected either by the height or the length of the wave, but only by the *elasticity* of the medium. Thus the harmony of a full band of music is perfect

even at a great distance; but this would be impossible unless loud sounds (high waves) and soft sounds (low waves), deep sounds (long waves) and sharp sounds (short waves), all run with the same velocity. But there is one exception here also which especially concerns us in the discussion of earth-waves. It is this: When the medium is very imperfectly elastic, and the waves are high, then the medium is *broken* by the passage of the waves at every step, its elasticity is diminished, and the waves *retarded.*

In order to understand clearly what follows, it is necessary to bear well in mind the distinction between *velocity of oscillation* and *velocity of transmission* or transit. These bear no relation to one another. Thus we may have a long, low water-wave moving with immense velocity along the surface, and yet communicating only a slow oscillating motion up and down to a boat resting on its surface. In the case of water-waves the velocity of transit depends on the length of the wave only, the *amount of vibration* on the height of the wave only, while the *velocity of vibration* depends on the relation of the height to the length. In elastic longitudinal waves the velocity of transit depends on the elasticity of the medium only; the amount of vibration, as in the last case, on the height of the wave, and the velocity of vibration upon the relation of height to length of wave.

Application to Earthquakes.—Suppose, then, a concussion of any kind to occur at a considerable depth (x, Fig. 94), say ten or twenty miles, beneath the earth-surface, S S. A series of elastic spherical waves will be generated, consisting of alternate compressed and rarefied shells, the whole expanding with great rapidity in all directions until they reach

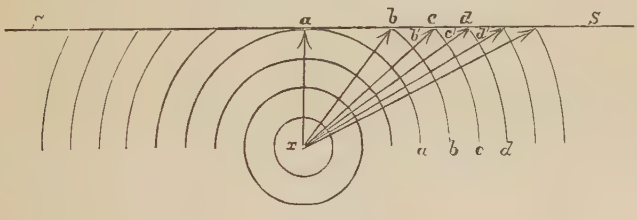


Fig. 94.

the surface at a. From this point of first emergence immediately above the focus x, the still-enlarging spherical shells would outcrop in rapidly-expanding *circular waves* similar in form to water-waves, but very different in character. This we will call the *surface-wave.* Fig. 94 is a vertical section through the focus x and the point of first emergence (epicentrum) a, showing the series of spherical waves outcropping at a, b, c, d, etc. The circles here drawn would equally represent a series of waves, or the same wave in successive degrees of enlargement.

This *surface-wave* would not be similar to any wave classified above.

It would not be a normal wave of any kind. It would be only the outcropping or emergence of the ever-widening spherical wave on the earth-surface. Both its velocity of transit along the surface, and the direction of its vibration in relation to the surface, will vary continually according to a simple law. The *direction of vibration*, being along the radii $x\ a$, $x\ b$, $x\ c$, etc., will be perpendicular to the surface at a, and become more inclined until it finally becomes parallel with the surface at an infinite distance. The *velocity of its transit* will be infinite at a, and then gradually decrease until, if we regard the surface as a plane surface, at an infinite distance it reaches its limit, which is the velocity of the spherical wave. Between these two extremes of infinity at a, and the velocity of the spherical wave at infinite distance, the velocity of the surface-wave varies inversely as the cosine, or directly as the secant, of the angle of emergence $x\ b\ a$, $x\ c\ a$, etc.

For, if $a\ a$, $b\ b$, $c\ c$, $d\ d$, etc., be successive positions of the spherical wave, then the radii $x\ a$, $x\ b$, $x\ c$, would be the direction both of propagation and of vibration. Now, when the wave-front is at b while the spherical wave moves from b' to c, the surface-wave would move from b to c; when the spherical wave moves from c' to d, the surface-wave moves from c to d, etc. If, therefore, $b\ c$, $c\ d$, etc., be taken very small, so that $b\ b'\ c$, $c\ c'\ d$, may be considered right-angled triangles, then in every position the surface-wave moves along the hypothenuse, while the spherical wave moves along the base of the small triangles $b\ b'\ c$, $c\ c'\ d$, etc. Letting $v =$ velocity of the spherical wave, and v' that of the surface-wave, and E the angle of emergence, we have the proportion—$v : v' :: 1 : sec.\ E$, and $v' = v.\ sec.\ E$, or if v is constant $v' \propto sec.\ E$. Therefore, at a, the point of first emergence, E being a right angle and $sec.\ E =$ infinity, $v' =$ infinity. At an infinite distance from a the angle E becomes 0, and the secant $= 1$, and $v' = v.\ 1 = v$. That is, at the point of first emergence the velocity of the surface-wave is infinite; from this point it decreases as the secant of the angle of emergence decreases, until finally at an infinite distance it becomes equal to the velocity of the spherical wave.

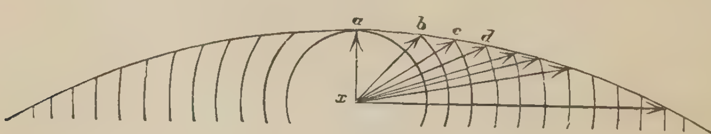


FIG. 95.

On a spherical surface (Fig. 95) it is evident that E never becomes 0, and therefore v' never reaches the limit v. If we conceived the wave to pass through the whole earth (Fig. 96), then the velocity of the surface wave would decrease to a certain point where E is a mini-

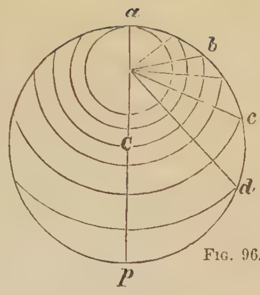


FIG. 96.

mum, say about c, and then would again increase to infinity on the other side of the earth, p, where E becomes again a right angle. If x be near the surface, v' would become nearly equal to v at some point of its course; but as x approaches the centre, C, the limit of v' would be greater and greater, until, if x is at the centre, v' would become infinite everywhere: i. e., a shock at the centre would reach the surface everywhere at the same moment.

Experimental Determination of the Velocity of the Spherical Wave.—On the supposition that earthquakes are really produced by the emergence on the surface of a series of elastic earth-waves, Mallet undertook to determine experimentally the velocity of such waves. Two stations were taken about a mile or more apart, and connected by telegraphic apparatus; a keg of gunpowder was buried at one, and at the other was placed an observatory, in which was a clock, a mercury mirror, and a light, the image of which reflected from the mercury mirror was thrown on a screen. The slightest tremor communicated to the mercury surface of course caused the image to dance. The moment of explosion was telegraphed; the moment of arrival of the earth-tremor was observed. The difference gave the *time* of transit; the distance, divided by the time, gave the velocity per second. In this manner Mallet found the velocity in sand 825 feet per second, or nearly nine and one-half miles per minute; in slate, 1,225 feet per second, or fourteen miles per minute; and in granite 1,665 feet per second, or nineteen miles per minute.[1] As an earthquake-focus is always several miles beneath the surface, and as rocks at that depth are probably as hard as granite, nineteen miles per minute may be taken as the average velocity of earth-waves as determined by these experiments. It agrees well with the observed velocity of many earthquakes.[2]

This result was unexpected, considering the law that all elastic waves in the same medium run with the same velocity, for the velocity of sound in granite or slate is probably not less than 10,000 or 12,000 feet per second. The explanation is to be found in the very imperfect coherence and elasticity of rocks. The medium is broken by the passage of large and high waves of the explosion, but carries successfully the small waves of sound.

Explanation of Earthquake-Phenomena.—Earthquakes have been divided into three kinds, viz., the *explosive*, the *horizontally progressive*, and the *vorticose*. The first kind is described by Humboldt as a violent motion directly upward, by which the earth-crust is broken up, and bodies on the surface are thrown high in the air. The shock

[1] Explosions at Hallett's Point gave a velocity of 5,000 to 8,000 feet per second (Abbot).

[2] Mallet, Second Report, "Transactions of the British Association, 1851."

is extremely violent, but does not extend very far. In the second, the shock spreads on the surface like the waves on water to a great distance. In the third there is a whirling motion of the earth entirely different from ordinary wave-motion. These three kinds are sometimes supposed to be essentially distinct, and possibly produced by different causes ; but we will attempt to show that the difference is wholly due to the different conditions under which the waves emerge on the surface. The three kinds are, in fact, often united in the same earthquake.

The most remarkable example of explosive earthquake is that which destroyed Riobamba in 1797. In this dreadful earthquake the shock came suddenly, like the explosion of a mine. Not only was the earth broken up and rent in various places, but objects lying on the surface of the earth were thrown violently upward ; bodies of men were hurled several hundred feet in the air, and afterward were found across a river and on the top of a hill. In earthquakes of this kind—1. The impulse is very powerful and sudden, so as to make a high but not a long wave, or, in other words, the velocity of vibration or of the shock is very great ; and, 2. The focus is not deep, so that the velocity of the shock (height of the wave) does not become small before it reaches the surface. At Riobamba the velocity of the shock was still very great when the wave reached the surface. From the distance bodies were thrown, Mallet supposes the velocity of the shock could not have been less than eighty feet per second (Jukes).

The *horizontally progressive kind* may be regarded as the true type of an earthquake; it is in fact the spreading surface-wave already explained. If the elasticity of the earth, and therefore the velocity of the waves, is the same in all directions, the surface-wave will spread in concentric *circles ;* but if the elasticity, and therefore the velocity of the waves, be greater in one direction than in another, as, for example, north and south than east and west, or the converse, then the form of the outcrop will be *elliptical.* In some rare cases the shock seems to run along a line. Thus progressive earthquakes have been subdivided into *circular*, *elliptical*, and *linear* progressive. We have already given the simple explanation of the first two ; the last may be briefly explained as follows :

Let it be borne in mind : 1. That these linear earthquakes usually run along mountain-chains ; 2. That most great mountain-chains consist of a granite axis (appearing along the crest and evidently connected beneath with the great interior rocky mass of the earth), flanked on each side with stratified rocks consisting of many different kinds ; 3. When elastic waves pass from one medium to another of different elasticity, in all cases a part of the waves passes through, but a part is always *reflected.* For every such change—for every layer—a reflection oc-

curs; and, therefore, if there are many such layers, the waves are quickly quenched. If, now, Fig. 97 represent a transverse section across such a mountain, and X the focus of an earthquake, it is evident that portion of the enlarging spherical wave which emerged along the axis a would reach the surface successfully; while those portions which

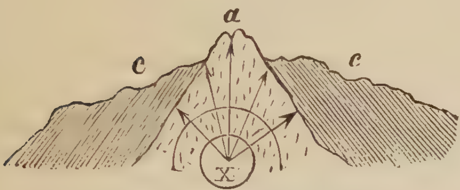


Fig. 97.—Diagram illustrating Linear Earthquakes.

Fig. 98.

struck against the strata of the flanks would be partially or wholly quenched. The mode of outcrop on the surface is shown in the map-view, Fig. 98, in which a is the epicentrum, b b the granite axis, and c c the stratified flanks.

The velocity of the surface-waves, as observed in many cases of severe earthquakes, is about twenty miles a minute. This accords well with Mallet's experiments in granite. In some earthquakes the velocity has been found to be twelve to fifteen miles (Mallet's results in slate), and in some as high as thirty to thirty-five miles per minute. In no *great* earthquake has the velocity been found higher than the last mentioned. In some *slight* shocks, however, occurring recently in New England, the velocity, as determined by telegraph, is estimated as high as one hundred and forty miles per minute, or 12,000 feet per second.

This amazing difference may be fully explained: It will be remembered that the velocity of the surface-wave is infinite at the epicentrum, and diminishes, according to a law already discussed, until it reaches, or nearly reaches, the velocity of the spherical wave. Now, if the earthquake-focus be comparatively shallow, the initial velocity of the surface-wave very rapidly approaches its minimum, and therefore the observed velocity of the surface-wave may be taken as nearly the same as that of the spherical wave; but, if the earthquake be very deep, the diminution, even on a *plane* surface, is far less rapid; and when we take into consideration the curvature of the earth-surface, it is evident that the velocity of the surface-wave is always and for all distances much greater than that of the spherical wave. This would well account for velocities of thirty to thirty-five miles, but not for one

hundred and forty miles. This latter is accounted for by another principle.

We have seen that these high velocities occur only in slight shocks. Now, while heavy shocks (large and high waves) break the medium at every step of their passage, and are therefore retarded, as already explained, slight tremors (small and low waves) are successfully transmitted without rupture, and therefore run with the natural velocity belonging to the medium, i. e., the velocity of sound. Now, the velocity of sound in granite is probably about 12,000 feet per second, or one hundred and forty miles per minute.

Vorticose Earthquakes.—In these cases the ground is twisted or whirled round and back, or sometimes ruptured and left in a twisted condition. The most conspicuous examples of this kind of motion occurred in the earthquake of Riobamba, and in the great Calabrian earthquake of 1783. In this latter earthquake the *blocks of stone forming obelisks were twisted one on another;* the earth was broken and twisted, so that *straight rows of trees were left in interrupted zigzags.* Phenomena similar to some of these were observed also in the California earthquake of 1868. Chimney-tops were separated at their junction with roofs, and twisted around without overthrow; wardrobes and bureaus turned about at right angles to the wall, or even with their faces to the wall.

Explanation.—Some of these effects—such as twisting of obelisks and chimney-tops, and turning about of bureaus, etc.—may be explained, as Lyell has shown, without any twisting motion of the earth at all, or any other than the backward and forward motion common to all earthquakes. Thus, if we place one brick on another, and shake them back and forth, holding only the lower one, they are almost certain to be left twisted one on the other. The reason is, that the adhesion is almost certain to be greater toward one end than the other—the centre of friction does not coincide with the centre of gravity. This is the probable explanation of twisted obelisks and chimney-tops, etc. Also, the simple back-and-forth shaking of a wardrobe in a diagonal direction would almost certainly lift up one end and swing it around. The vorticose motion in such cases is probably not real, but *only apparent.*

But there are other cases of undoubtedly *real* vorticose motion; as, for example, straight rows of trees changed into interrupted zigzags by fissures and displacement. All such cases of *real twisting* are probably explicable on the principle of *concurrence and interference of waves.* If two systems of waves of any kind meet each other, there will be points of concurrence where they *reënforce each other*, and points of interference where they *destroy each other.* Suppose, for instance, a system of water-waves, represented by the double lines *i, i*

(Fig. 99), running in the direction *b b*, strike against a wall, *w w*: the waves would be reflected in the direction *c c*, and are represented by the single lines *r*, *r*. Then, if the lines represent crests, and the intervening space the troughs, at the places marked with crosses and dots there would be concurrence, and therefore higher crests and deeper

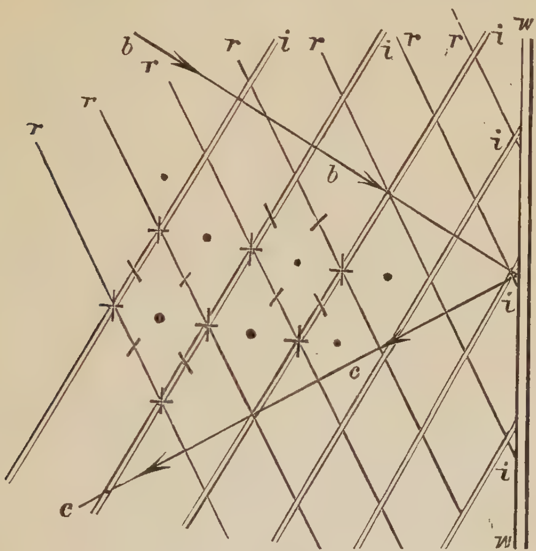


FIG. 99.—Diagram illustrating Reflection of Waves.

troughs, while at the points indicated by a dash there would be interference and mutual destruction, and therefore smooth water. The same takes place in earth-waves. If two systems of earth-waves meet and cross each other, we must have points of concurrence and interference in close proximity. The ground, therefore, will be thrown into violent agitation—points in close proximity moving in opposite directions (twisting). If the motion be sufficient to rupture the earth, restoration is not made by *counter-twisting*, and the earth is left in a displaced condition.

The causes of interference may be various—sometimes difference of velocity of waves, already explained, by which some overrun others, concurring and interfering; more often it is the result of reflection from surfaces of different elasticity. For example, it is well known that the most violent effects of earthquakes, especially twisting of the ground, usually occur near the junction of the softer strata of the plains with the harder and more elastic strata of the mountains. Now, suppose from a shock at *X* (Fig. 100) a system of earth-waves should emerge at *a*, and run as a surface-wave toward the mountain *m*. The

waves, striking the hard, elastic material *m*, would be partly transmitted and partly reflected. The reflected waves, running in the direction of the arrow *r*, would meet the advancing incident waves moving in the direction of the arrow *i*, and concurrence and interference would be inevitable.[1]

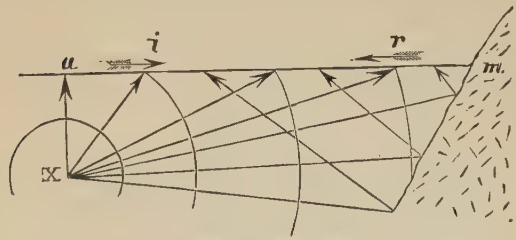


FIG. 100.—Reflection of Earthquake-Waves.

Minor Phenomena.—Not only the several kinds of earthquakes, but many of the minor phenomena, are explained by the wave-theory.

1. *Sounds.*—These are usually described as a *hollow rumbling, rolling*, or *grinding ;* sometimes as clashing, thundering, or cannonading. They are probably produced by rupture of the earth at the *origin*, and by the passage of the wave through the imperfectly elastic rocky medium, *breaking the medium and grinding the broken parts together.* But what is especially noteworthy is, that these sounds *precede* as well as accompany the shocks. In every earthquake there are transmitted waves of every variety of size. The great waves are sensible as shocks, or jars, or tremors; the very small waves, too small to be appreciated as tremors, are heard as sounds. But, as already explained, these last run with greater velocity in an imperfectly coherent medium like the earth, and therefore arrive sooner than the great waves, which constitute the shock. The same was observed in Mallet's experiments.

2. *Motion.*—As to *direction*, the observed motion is sometimes vertically *up and down*, sometimes horizontally *back and forth*, and sometimes *oblique* to the horizon. Almost always a *rocking motion*, i. e., a leaning of tall objects first in one direction and then in the other, is observed. As to *violence* or velocity of motion, this is sometimes so great that objects are thrown into the air, and whole cities are shaken down as if they were a mere collection of card-houses, while in other cases only a slow swinging, or heaving, or gentle rocking, is observed.

The difference in *direction* is wholly due to the position of the observer. At the epicentrum it is of course *vertical*, and thence it becomes more and more oblique, until at great distances it is usually *horizontal.* The *violence* of the shock or *velocity* of ground-motion depends partly upon the violence of the original concussion, and partly on the distance from the origin or *focus.* This velocity of the ground-motion must not be confounded with the velocity of the wave already discussed. The latter is the velocity of *transit* from place to place; the

[1] For an excellent discussion of the effects of interference of earth-waves, *see* a memoir by Prof. John Milne, "Transactions of the Seismological Society of Japan," vol. i., Part II., p. 82.

former is the velocity of *oscillation* up and down, or back and forth. The velocity of oscillation has no relation to the velocity of transit, but depends only on the height of the wave, which constantly diminishes and becomes finally very small, though the velocity of transit remains the same, and always enormously great. The *rocking motion* is also easily explained. A series of waves, somewhat similar in form to water-waves (though differing in nature), actually passes beneath the observer. Of course, when an object is on the *front-slope*, it will lean in the direction of transit; and, when on the *hind-slope*, in the contrary direction.

3. *Circle of Principal Destruction.*—In some earthquakes a certain zone at considerable distance from the point of first emergence (epicentrum) has been observed, in which the destruction by overthrow is very great, and beyond which it speedily diminishes. This has been called the circle of principal destruction or overthrow. It is thus explained: The overthrow of buildings depends not so much on the *amount* of oscillation as upon the horizontal element of the oscillation. Now, the whole amount of oscillation is greatest at the point of first emergence, and decreases outward; but the horizontal element is nothing at *a*, and increases as the cosine *E*. Therefore, under the influence of these two conditions, one decreasing the whole oscillation, the other increasing the horizontal element of that oscillation, it is evident that there will be a point on every side, or, in other words, a circle, where the horizontal element will be a maximum. This is shown in Fig. 101, in which $a\,a'$, $b\,b'$, $c\,c'$, etc., are the decreasing oscilation, and $b\,b''$, $c\,c''$, are the horizontal element. This reaches a maximum at *c*. It has been found by mathematical calculation, based upon the supposition that the whole oscillation varies inversely as the square of the distance from *X*, that the horizontal element will be a maximum when the angle of emergence is 54° 44′. By determining by observation the circle of principal disturbance, it is easy to calculate the depth *a X* of the focus, for it will be the apex of a cone whose base is that circle, and whose apical angle is 70° 32′.[1]

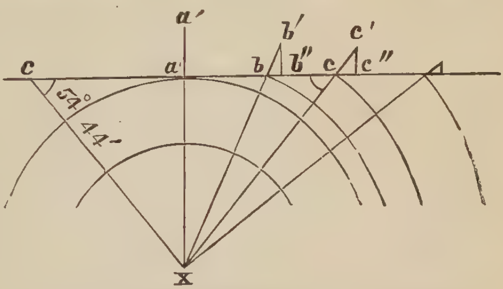


FIG. 101.—Diagram illustrating Circle of Principal Disturbance.

4. *Shocks more severely felt in Mines.*—It has been sometimes observed that shocks are distinctly felt in mines which are insensible at the surface. This is probably explained as follows: Let *S S* (Fig. 102) be the surface of the ground; and let *a b* represent hard, elastic strata, covered with loose, inelastic materials, *c c*. Now, if a series of waves

[1] Mallet's "Report for 1858," p. 101.

come in the direction of the arrows *d d*, and, passing through *a b* on their way to the surface, strike upon the lower surface of *c c*, a portion would reach the surface by refraction, but a portion would be reflected and return into *a b*, concurring and interfering with the advancing waves, and producing great commotion in these strata.

5. *Shocks less severe in Mines.*—This case is probably more common than the last. It was notably the case in the earthquake of 1872 in

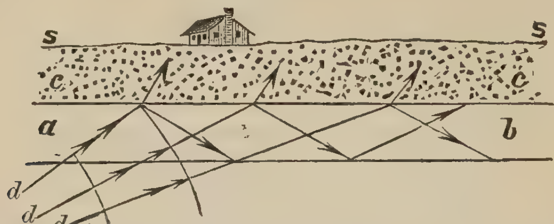


Fig. 102.—Shocks in Mines.

Inyo County, California. While the surface was severely shaken, many houses destroyed, and large fissures formed in the earth, the miners, several hundred feet below the surface in the hard rock, scarcely felt it at all. This is probably, at least partly, explained as follows: As long as the wave travels within the earth, motion of the particles is restrained by the work of elastic compression; but, as soon as the surface is reached, the motion becomes free, and the velocity of shock is far greater than before, often so great as to throw bodies high in the air. The phenomenon is exactly like that in the familiar experiment of the ivory balls: when the first in the series is struck, an elastic wave of compression passes through all, but only the last one moves.

6. *Bridges.*—In a somewhat similar manner are to be accounted for

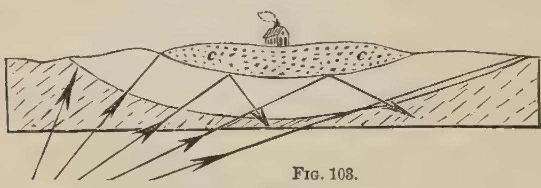


Fig. 103.

the phenomena of bridges. In the earthquake-regions of South America there are certain favored spots, often of small extent, which are partially exempt from the shocks which infest the surrounding country. The earthquake-wave seems to pass under them as under a bridge, to reappear again on the other side. The mere inspection of Fig. 103 will explain the probable cause of this exemption, viz.: reflection from the under surface of an isolated mass of soft, inelastic strata, *c c*.

7. *Fissures.*—The ground-fissures, so commonly produced by earthquakes, are sometimes of the nature of the *great fissures* of the crust, which are the probable cause of earthquakes. Such great fissures are

usually wholly beneath the surface at great depth, but sometimes may break through and appear on the surface. This is certainly the case when *decided faults* occur with elevation or depression of large tracts of land. But the surface-fissures so frequently described, small in size, very numerous, and running in all directions, have an entirely different origin. They are evidently produced by the shattering of the softer, more incoherent, and inelastic surface-soil, and by the passage of the earth-wave. Even the more elastic underlying rock is broken by the same cause, but to a much less extent.

Earthquakes originating beneath the Ocean.

We have thus far spoken of earthquakes originating beneath the land-surface. But three-fourths of the earth-surface is covered by the sea; and we have already seen that other forms of igneous agency are most abundant in and about the sea. As we might expect, therefore, the greater number of earthquake-shocks occur beneath the sea-bed. In such, the phenomena already described are complicated by the addition of the "*Great Sea-Wave.*"

Suppose, then, an earthquake-shock to occur beneath the sea-bed: the following waves will be formed: 1. As before, a series of elastic spherical waves will spread from the focus, until they emerge on the sea-bed. 2. As before, a series of circular surface-waves, the outcrop of the spherical waves, will spread on the sea-bottom until they reach the nearest shore, and perhaps produce destructive effects there. 3. On the back of this submarine earth-wave is carried a corresponding sea-wave. This is called the "*forced sea-wave*," since it is not a free wave, but a forced accompaniment of the ground-wave beneath. It reaches the shore at the same time as the earth-wave. It is of little importance. 4. In addition to all these is formed the great sea-wave or tidal wave.

Great Sea-Wave.—This common and often very destructive accompaniment of earthquakes is formed as follows: The sudden upheaval of the sea-bed lifts the whole mass of superincumbent water to an equal extent, forming a huge mound. The falling again of this water as far *below* as it was before *above* its natural level generates a *circular wave of gravity*, which spreads like other water-waves, maintaining its original wave-length, but gradually diminishing its wave-height until it becomes insensible. Usually, a *series* of such waves is formed by the motion of the sea-bottom up and down several times. These waves are often 100 to 200 miles across their base (wave-length) and fifty to sixty feet high at their origin. Their destructive effects may be inferred from the enormous quantity of water they contain. In the open sea they create no current, and are not even perceived, but, when they touch bottom near shore, they rush forward as great breakers fifty or sixty feet high, sweeping away everything in their course.

Being waves of gravity, their velocity, though very great on account of their size, is far less than that of the earth-waves, and they reach the neighboring shore, therefore, some time later, and often complete the destruction commenced by the earth-waves.

Examples of the Sea-Wave.—In the great earthquake which destroyed Lisbon in 1755, the epicentrum was on the sea-bed fifty or more miles off the coast of Portugal. From this point the surface earth-waves spread along the sea-bottom until they reached shore. It was the arrival of these waves which destroyed Lisbon. About a half-hour later, when all had become quiet, several great sea-waves, one of them sixty feet high, came rushing in, deluging the whole coast and completing the destruction commenced by the earth-waves. This wave was thirty feet high at Cadiz, eighteen feet at Madeira, and five feet on the coast of Ireland. It was sensible on the coast of Norway, and even on the coast of the West Indies, after having crossed the whole breadth of the Atlantic.

In 1854 a great earthquake shook the coast of Japan. Its focus was evidently beneath the sea-bed some distance off the coast, for, in about a half-hour, a series of water-waves thirty feet high rushed upon shore and completely swept away the town of Simoda. From the same centre the waves, of course, spread in the contrary direction, traversed the whole breadth of the Pacific, and in about twelve and a quarter hours struck on the coast of California at San Francisco, and swept down the coast to San Diego. These waves were thirty feet high at Simoda, fifteen feet high at Peel's Island, about 1,000 miles off the coast of Japan, 0.65 feet, or eight inches, high at San Francisco, and six inches at San Diego.[1]

On the 13th of August, 1868, a great earthquake desolated the coast of Peru. Its focus was evidently but a little way off shore, for in less than a half-hour a series of water-waves fifty or sixty feet high rushed in and greatly increased the devastation commenced by the earth-waves. These waves reached Coquimbo, 800 miles distant, in three hours; Honolulu, Sandwich Islands, 5,580 miles, in twelve hours; the Japan coast, over 10,000 miles, the next day. They were also observed on the coast of California, Oregon, and Alaska, over 6,000 miles in one direction, and on the Australian coast, nearly 8,000 miles in another direction. This series of waves was distinctly sensible at a distance of nearly half the circumference of the earth. Had it not been for the barrier of the South American Continent, it would have encircled the globe.[2]

There are several points in the above description which we must very briefly explain:

1. The velocity of these great sea-waves, though less than that of

[1] "Report of Coast Survey for 1862." [2] "Report of Coast Survey for 1869."

the earth-waves, is still very great in comparison with ordinary sea-waves. The waves of the Japan earthquake crossed the Pacific to San Francisco, a distance of 4,525 miles, in a little more than twelve hours, and therefore at a rate of 370 miles per hour, or over six miles per minute. The waves of the South American earthquake of 1868 ran to the Hawaiian Islands at a rate of 454 miles per hour. This amazing velocity is the result of the great *size of these waves.*

2. The *size* of these great waves is determined by multiplying the *time* of oscillation by the velocity, on the well-known principle that every kind of wave runs its own length during the time of one complete oscillation. The velocity is obtained by observing the time at different points. The time of oscillation is determined by means of tidal gauges. The tidal gauges established by the coast survey on the Pacific coast showed that the time of oscillation of the larger waves of the Japan earthquake was about thirty-three (thirty one to thirty-five) minutes. This would give a wave-length of a little over 200 miles. It is probable that the wave-length in the case of the South American earthquake was at least equally great.

3. The distance to which the sea-waves run is far greater than that of the earth-waves. The former is distinctly sensible for 10,000 miles; the latter very rarely more than a few hundreds. There are two reasons for this: 1. All waves diminish in oscillation (wave-height) as they spread from the origin, because the quantity of matter successively involved in the oscillation constantly increases. But in the one case the matter involved lies in the circumference of a circle; in the other, in the surface of a sphere; therefore, the one increases as the distance, the other as the square of the distance. Therefore, the decrease of oscillation (height of wave) is far less rapid for water-waves than for elastic spherical waves. 2. A still more effective reason is this: Water-waves run in a perfectly homogeneous medium, and therefore diminish only according to the regular law just stated; but the earth-waves run in an heterogeneous, imperfectly elastic, and imperfectly coherent medium, and therefore they are rapidly quenched and dissipated by repeated refractions and reflections, and by repeated fractures of the medium, and thus changed into other forms of force, as heat, electricity, etc. Were it not for this, the destructive effects of earthquakes would be far more extensive.

4. We have said the wave-length remains unchanged. This length, therefore, represents the diameter of the original water-mound, and therefore of the original sea-bottom upheaval. In the Japan earthquake this was 200 miles across. This shows the grand scale upon which earthquake-movements take place.

5. As already explained, earthquake sea-waves differ from all other sea-waves in that their great size makes them drag bottom even in open

deep sea. In their case, therefore, the velocity depends not only on the wave-length, but also *on the depth of the sea.* Knowing the size (wave-length) of these waves, and therefore what ought to be their *free velocity*, and also knowing their *actual velocity* by observation, the difference gives the *retardation* by dragging; and by the retardation may be calculated the mean depth of the ocean traversed. In this way it has been determined that the mean depth of the Pacific between Japan and San Francisco is 12,000 feet, and between Peru and Honolulu, Sandwich Islands, 18,500 feet. The great importance of such results is obvious.

Depth of Earthquake-Focus.

The great obscurity which hangs about the subject of the interior condition of the earth and the ultimate cause of igneous agencies renders any positive knowledge on these subjects of peculiar interest. There can be little doubt that the phenomena of earthquake-waves, their form, their velocity, their angle of emergence, etc., if once thoroughly understood, would be a most delicate index of this condition, and a powerful means of solving many problems which now seem beyond the reach of science. Among problems of this kind none is more important, and at the same time more capable of solution, than the depth of the origin of earthquakes, and therefore presumably of volcanoes.

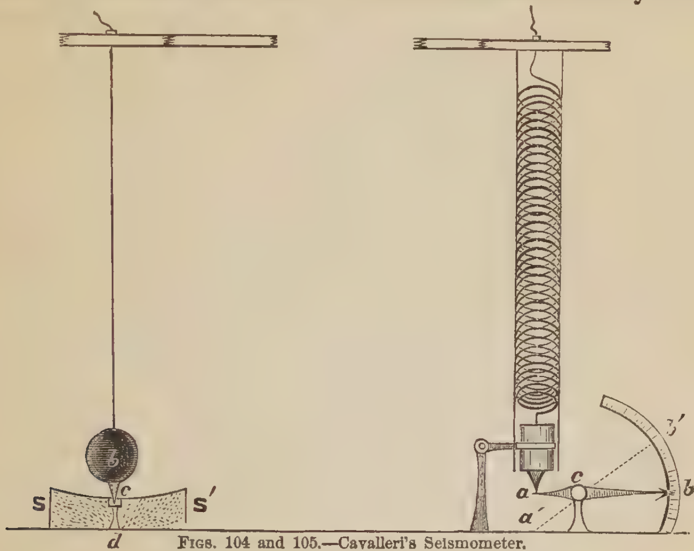
Seismometers.—The most direct way of determining the depth of an earthquake-focus is by means of well-constructed seismometers. These are instruments for measuring and recording earthquake-phenomena. . They are of infinite variety of forms, depending partly upon the facts desired to be recorded, and partly upon the mode of record. As examples we will mention only two:

An excellent instrument for recording slight tremors is one invented and used by Prof. Palmieri, of the Vesuvian Observatory. It consists of a telegraphic apparatus with the usual paper-slip and stile. The paper-slip, accurately divided into hours, minutes, and seconds, travels at a uniform rate by means of clock-work. The battery-circuit is closed and opened, and the recording stile worked by the shaking of a metallic bob, hung by a delicate spiral spring above a mercury-cup; the shaking of the bob being determined by the tremor of the earth. Such an instrument records the exact moment of occurrence of earthquake-shocks, however slight; also, the moment of passage of every wave and its time of oscillation; and if there be more than one such instrument, the moment of occurrence at different places gives the velocity of the surface-wave v'. It *records*, however, rather than *measures* earthquake-phenomena; it is a seismograph rather than a seismometer.

The best form of seismometer which we have seen described—that which gives the most important information—is that of Prof. Cavalleri, of Monza.[1] It consists essentially of two pendulums, one horizontally

[1] *Philosophical Magazine*, vol. xix., p. 102, 1860.

and the other vertically oscillating (Figs. 104 and 105). The former (Fig. 104) is an ordinary pendulum, with a heavy bob, *b*, armed with a stile which touches a bed of sand, *s s*. The sharp point of the stile rests loosely in a slight depression in a small flat cylinder or button, *c*, resting lightly on the top of the firm column *d*. When the earthquake-shock arrives, the whole building, and therefore the attachment *a*, above, and the bed of sand, *s s*, on the floor, will move in the direction of the shock. This direction will generally be partly horizontal and partly vertical (*x b*, *x c*, *x d*, Fig. 94). We will consider now only the hori-



Figs. 104 and 105.—Cavalleri's Seismometer.

zontal element. The pendulum, *b*, will tend to retain its position, and the bed of sand will move beneath it, first in one direction and then in the other, and the stile will thus mark the sand back and forth to a distance equal to the back-and-forth motion of the earth. The direction from which the impulse came is determined by the side on which the little cylinder falls. It is easy to connect the pendulum with a clock set at twelve, in such wise that the motion of the former will instantly set the latter going. The difference between this clock-time and the real time will give the *instant of transit*. It is clear that this pendulum does not give the whole amount of the vibration or motion of the shock, but only the horizontal element. If *a b* (Fig. 106) represent the direction and amount of vibration, then *a c* is the horizontal element measured by the pendulum. This instrument, therefore, gives the moment of transit, the direction of transit, and the horizontal element of vibration.

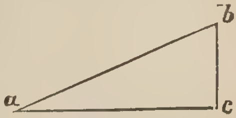


Fig. 106.

The vertical element, *b c*, of the vibration is

given by a vertically oscillating pendulum (Fig. 105), the point of which rests lightly on one arm, a, of a very easily-moved lever, the other arm, b, of which acts as an index by means of a graduated quadrant. When the shock moves the floor of the building upward, the heavy weight of the pendulum retaining its position by stretching of the wire spring, the arm a is pressed against the stile, and the arm b is elevated; when the floor descends again, b is retained in its elevated position by a ratchet at c, and thus records the amount of elevation of the floor. This pendulum, therefore, gives the upward movement or one-half the whole vertical element. Having now the horizontal and vertical element, i. e., the base and perpendicular of a right-angled triangle, the hypothenuse, or whole oscillation, and the direction of oscillation, or angle of emergence (a, Fig. 106), are gotten by simple calculation ($a\ b = \sqrt{a\ c^2 + b\ c^2}$, and $b\ c = a\ b.\ \sin a$), or by accurate plotting.

The important facts recorded by this instrument are: 1. The *instant of transit ;* 2. The *direction of transit ;* 3. The direction of oscillation, or *angle of emergence ;* 4. The *amount of oscillation.* From these elements (if we have several seismometers scattered about the country) may be calculated : 1. The *velocity of transit ;* 2. The *position of the focus ;* 3. The *form of the focus*, whether point or fissure ; 4. The *force of the original concussion.* The most important of these are the position and depth of the focus.[1]

The Determination of the Epicentrum.—Cavalleri's seismometer gives the direction of transit of the surface-wave. If, by the use of many such seismometers, or even by rougher methods, we get a number of these surface-lines of transit, by following these back we get the epicentrum at their intersection. Or if, by means of many seismographs giving time of transit, or even by observatories or stations of any kind with accurate clocks, we get several points of simultaneous arrival of the wave, then by drawing a curve through these points we have a coseismal curve. A perpendicular drawn from the middle point of the line joining any two of these points will pass through the epicentrum, and two such perpendiculars would determine its position. Fig. 107 represents coseismal curves, and b, c, d, three points on the curve ; a is the epicentrum.

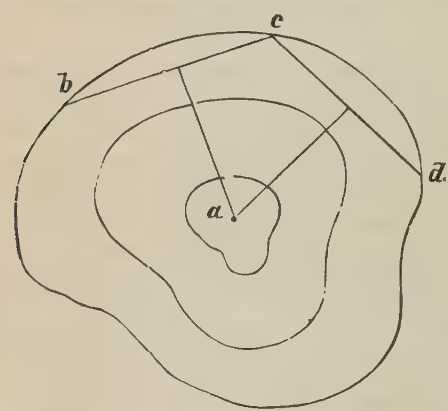


Fig. 107.—Coseismal Lines.

[1] Probably the best seismometers yet proposed are those recently used in Japan. (*See* "Transactions of the Seismological Society of Japan," vol. i., Part I.)

Determination of the Focus.—The spherical wave is a wave of longitudinal oscillation. The direction of oscillation, therefore, is the same as the direction of transmission (wave-path), which is the radius of the agitated sphere. If, therefore, the direction of the ground-motion (the line *a b*, Fig. 106) be followed into the earth, it carries us back along the wave-path to its origin, the focus. Two such wave-paths by their intersection would determine its position. Thus, in Fig. 108, if *c* and *b* be the position of two seismometric observatories, the angles

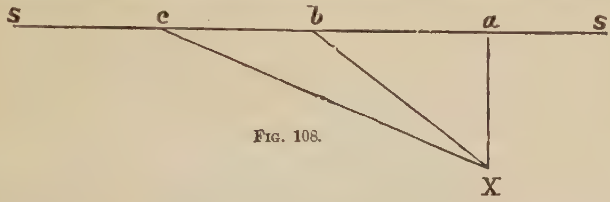


Fig. 108.

of emergence, *x c a* and *x b a*, being given by observation, and the distance, *c b*, being known, we have all the elements necessary to determine either by calculation or by accurate plotting the wave-paths *c x* and *b x*, and their point of intersection *x*, and therefore of the depth *a x*.

Although seismometers, such as we have described, are necessary for accurate results from few observations, yet by multiplying the observations, even by rough methods, approximative results may be obtained. We will mention only two examples :

In 1857 a terrible earthquake shook the territory of Naples, destroying many towns and villages, and killing about 10,000 people. The scene of destruction was visited soon after by Mr. Mallet. By careful examination of overthrown objects, many lines of transit of the surface-wave were determined, which, protracted, carried him with considerable certainty to the epicentrum ; similarly many lines of emergence, or paths of the spherical wave, protracted back, conducted to the focus. This focus was determined to be not a point, but a *fissure, nine miles long and through three miles of solid rock.* The centre of this rent was about six miles beneath the surface.[1]

In 1874 a not very severe earthquake shook Central Germany. It has been thoroughly investigated by Seebach. The epicentrum was determined with great precision by erecting perpendiculars to the bisected chords of the coseismal curves. The focus was determined as a rent through four miles of rock, the centre of the rent being nine or ten miles in depth.[2]

The velocity of transit of the waves of the Naples earthquake was 860 feet per second, or between nine and ten miles per minute ; that of the earthquake of Middle Germany was about twenty-eight miles per minute.

[1] Mallet, "Principles of Seismology." [2] Seebach, "Das Mittel Deutsche Erdbeben."

There have been many attempts to determine the depth of earthquakes by other methods, especially by using the relative velocities of the spherical and the surface waves as a means of getting the angle of emergence $\left(\text{sec. } E=\frac{v'}{v}\right)$; but such a method is evidently valueless, because the velocity of the spherical wave (v) is not constant.[1]

Effect of the Moon on Earthquake-Occurrence.—By an extensive comparison of the times of occurrence of several thousand earthquakes with the positions of the moon, Alexis Perrey has made out with some probability the following laws: 1. Earthquakes are a little more frequent when the moon is on the *meridian* than when she is on the horizon. 2. They are a little more frequent at new and full moon (syzygies) than at half-moon (quadratures). 3. They are a little more frequent when the moon is nearest the earth (perigee) than when she is farthest off (apogee). Now, if these laws are really true, it would seem that there is a *slight* tendency for earthquakes to follow the law of tides: for the first law gives the time of flood-tide, and the second and third the times of highest flood-tide. It would seem, therefore, that the attraction of the sun and moon has a perceptible effect in determining the time of occurrence of earthquakes. Many geologists regard these laws, if established, as conclusive proof of the general fluid condition of the earth beneath a comparatively thin crust. This interior liquid they suppose to be influenced by the tide-generating forces of the sun and moon; but, if this were true, the effect ought to be far greater than we find it. Whatever be the interior condition of the earth, the effect of the moon on the meridian would be to *assist*, and on the horizon to *repress*, any force whatsoever tending to break up the crust of the earth and to produce an earthquake.

Relation of Earthquake-Occurrence to Seasons and Atmospheric Conditions.—By extensive comparison of earthquake-occurrence with the seasons, it has been shown that they are a trifle more frequent in winter than in summer. Constructing a curve representing the annual variation of earthquake-intensity, this curve rises to its maximum in January and sinks to its minimum in July. But the difference is small. There has been no satisfactory explanation of this fact.

There is an almost universal popular belief in earthquake-regions that the occurrence is preceded by a still, oppressive state of the air. Although no scientific investigations have confirmed this impression, yet it seems quite possible and even probable that diminished atmospheric pressure, indicated by a low state of the barometer, may act as a determining cause of earthquake-occurrence, precisely as the position of the moon on the meridian. In both cases, however, we must regard

[1] But although it is impossible thus to find the depth of the focus *directly*, yet indirectly it may be found, as Seebach has shown, by the *rate of decrease* of the velocity of the surface-wave (v'). The deeper the focus, the slower the rate of decrease from infinity at the epicentrum.

these not as true causes of earthquakes, but only as causes determining the moment of occurrence.

Section 4.—Gradual Elevation and Depression of the Earth's Crust.

Of all the effects of igneous agencies these are by far the most important. Although not violent and destructive like volcanoes and earthquakes, although indeed so little conspicuous as to be generally unobservable except to the eye of science, yet, acting not paroxysmally but constantly, not in isolated spots but over wide areas and affecting whole continents, their final result in modifying the crust of the earth and making history is far greater than that of all other igneous agencies put together. It is probable that the same causes which are now at work gradually raising or depressing the earth's crust have during geological times formed the continents and the seas.

Elevation or Depression during Earthquakes.—We have already spoken (page 105) of sudden elevations or depressions of very great areas of country at the time of earthquake-occurrence in Hindostan, in the valley of the Mississippi River, and especially of the southern part of South America. It is not probable, however, that much is accomplished in this paroxysmal way. These cases are referred to in order to show the close connection of such sudden bodily movements, and therefore presumably, also, of the slower movements about to be described, with the causes and forces which produce earthquakes.

Movements not connected with Earthquakes—South America.—Besides the sudden elevation of Chili and Patagonia by earthquakes, the same countries show evidences of gradual elevation on a stupendous scale. The evidences are old sea-beaches, full of shells of species now living in the adjacent sea, far above the present water-level. These "*raised beaches*" have been traced 1,180 miles on the eastern shore and 2,075 miles on the western, and at different levels from 100 to 1,300 feet above the sea. More recently Alexander Agassiz has traced them by means of corals still sticking to the rocks to the height of 3,000 feet. It is not probable that all this movement took place during the present geological epoch, but it is the more instructive on that very account, since it shows the identity of geological causes with causes now in operation.

Italy.—The most carefully-observed instance of gradual depression and elevation is that of the coast of Naples. Fig. 109 is a map and Fig. 110 a section of the coast of the bay of Baiæ, near Naples. Between *a a a*, the present coast-line, and the cliff *b b b*, which marks the position of the former coast-line, there is a nearly level plain called the Starza. Now, there is perfect evidence that at one time the land was depressed until the sea beat against the cliff *b b*, and that both

the depression and the reëlevation to its present condition took place since the period of Roman greatness. The evidence is as follows:

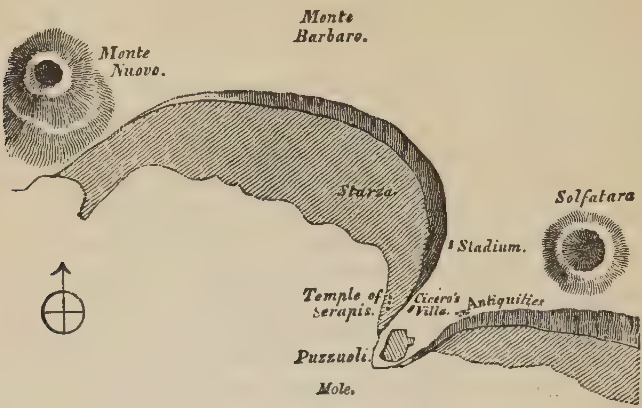


Fig. 109.

1. There are certain shells abundant in the Mediterranean and in many other seas, called *lithodomus* (λιθος, a stone; *domus*, a house), from their habit of boring for themselves holes in the rocks near the water-line. Such borings, often with the dead shells in them, are found all along the base of the cliff *b b*, twenty feet above the present sea-level. 2. The level plain called

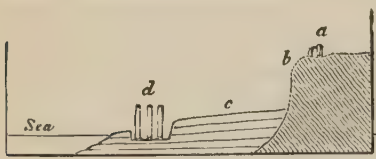


Fig. 110.

Starza is composed of strata containing shells of the Mediterranean and Roman works of art. 3. On this plain, near the present sea-margin, are the ruins of a Roman temple dedicated to Jupiter Serapis. The floor and three of the columns of this beautiful work are still almost perfect (Fig. 110). When first discovered the floor and the lower part of the columns were covered by the materials of the plain. Above the part thus covered the columns were bored with *lithodomi* to a height of twenty feet. This temple was, of course, above the sea-level during the Roman period. After that period it sank until the sea-level stood at *s′* (Fig. 110), twenty feet above the base. Now, the floor of the temple is again on a level with the sea. These changes were so gradual that they were entirely insensible, and, in fact, unknown to the inhabitants. The upright position of the columns also shows that it could not have been produced by convulsive action. 4. Italian historians state that in 1530 the sea beat against the cliff *b b*. 5. Evidences of similar changes, in some cases depression and in others elevation, are seen in many places along the coast of Italy, Candia, and Greece.

In all the cases thus far mentioned, but especially that of the temple of Serapis, the near vicinity of volcanoes (Fig. 109) suggests that these effects were probably in some way connected with volcanic action. But there are many instances in which no such connection can be traced.

Scandinavia.—The best-observed instance of this kind is that of the coasts of Norway and Sweden. Careful observations on the coasts of the Baltic and Polar Seas have proved that nearly the whole of Norway and Sweden is rising slowly, and has been rising for thousands of years. South of Stockholm there is no elevation, but, on the contrary, slight *depression;* but north of Stockholm the whole coast is rising at a rate which increases as we go north until it attains a maximum at the North Cape of five to six feet per century. These observations were made under the direction of the Swedish Government by means of permanent marks made at the sea-level, and examined from year to year. That similar changes have been in progress for thousands of years, and have greatly increased both the height and the extent of these countries, is proved by the fact that *old sea-beaches*, full of shells of species now living in the neighboring seas, are found fifty to seventy miles inland, and 100, 200, and even 600 feet above the present sea-level. In some places, the country rock, when uncovered by removing superficial deposit of beach-shells, is found studded with barnacles like those which mark the present shore-line (Jukes).

The rising area is about 1,000 miles long north and south, and of unknown breadth. It may embrace a considerable portion of Russia. Lyell estimates the average rate as not more than two and a half feet per century. At this rate, to rise 600 feet would require 24,000 years.[1] Similar raised beaches are found in nearly all countries. We give these as examples of an almost universal phenomenon, which will be again more perfectly described in the chapter on the Quaternary.

Greenland.—For obvious reasons, evidences of *elevation* are much more conspicuous than evidences of *depression.* One of the best-observed instances of the latter is that of the coast of Greenland. This coast is now sinking along a space of 600 miles. Ancient buildings on low rock-islands have been gradually submerged, and experience has taught the native Greenlander never to build his hut near the water's edge.

Deltas of Large Rivers.—In the deltas of the Mississippi, the Ganges, the Po, and many other large rivers, there are unmistakable evidences of gradual depression. These evidences are fresh-water shells, and planes of vegetation, or *dirt-beds*, far below the present level of the sea. A section of the delta deposits of the Mississippi River reveals the fact that these deposits consist of river sands and clays, *s*, *cl*

[1] Lyell's "Antiquity of Man," p. 58.

(Fig. 111), containing *fresh-water shells*, with now and then an intercalated stratum of marine origin, *l*, containing *marine* shells, and at uncertain intervals distinct lines *of turf* or *vegetable soil*, *g'*, *g''*, each with the stumps and roots of cypress-trees as they originally grew. Each one of these turf-lines is a *submerged forest-ground*, except the uppermost, which is the present forest-ground. Precisely similar phenomena have been observed in other large deltas. The deltas of the Ganges and the Po have been penetrated more than 400 feet without reaching bottom. In both the deposit is made up of fresh-water strata alternating with *dirt-beds* or forest-grounds. These facts prove that these great deltas have been at intervals during the whole period of their formation, as they are now, *fresh-water* swamps, overgrown in parts with trees, etc.; that they have steadily subsided to a depth indicated by the thickness of the deposit containing the old forest-levels; that the upbuilding by river-deposit has gone on *pari passu*, so as to maintain nearly the same level all the time; but that from time to time the subsidence was more rapid, so that the sea gained possession for a while until it was again reclaimed by river-deposit, and again more slow, so that the area was again thoroughly covered with forests, and so on. These facts are of great importance in geology, and will be frequently referred to in the following pages.

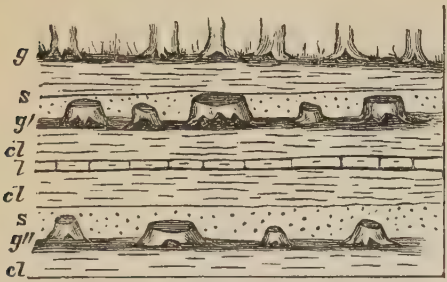


Fig. 111.

Southern Atlantic States.—Evidence of a similar kind proves that a large portion of the coasts of our Southern Atlantic States is slowly subsiding at the present time, though there are also evidences, in the form of raised beaches, of *elevation* immediately preceding the present subsidence. The evidences of subsidence are most conspicuous along the coast of South Carolina and Georgia. They consist of cypress-stumps *in situ* below the present tide-level.

These facts seem to point to the conclusion that subsidence is going on in nearly all places where large deposits of sediment are accumulating.

Pacific Ocean.—But by far the grandest example of subsidence known is that which has been going on for thousands, probably hundreds of thousands, of years, and is still going on in the mid-Pacific Ocean. The subsiding area is situated under the equator, and is about 6,000 miles long, by about 2,000 to 3,000 miles wide. The evidence of the subsidence and its rate is entirely derived from the study of coral-reefs

in this region. The further discussion of the subject will be deferred until we take up coral-reefs.

Our examples, be it observed, are all taken from the vicinity of coast-lines, the sea-level being used as term of comparison. In the interior of continents, and in the midst of the sea where there are no islands, we have no such means of detecting changes, yet it is precisely there, i. e., in the middle of the rising or subsiding area, that the changes are probably the greatest.

Theories of Elevation and Depression.

It is evident that observation only determines changes of *relative* position of sea and land. These changes may be the result of rise and fall of sea, or rise and fall of land. The popular mind naturally attributes them to the rise and fall of the sea, as the more unstable element. But, by the principle of hydrostatic level, it is clearly impossible that the ocean should rise or fall *permanently* at one place without being similarly affected everywhere. It is certain, therefore, that the changes we have described above, being in different directions in different places, must be due to *movements of the solid crust.* Nevertheless, it is also true that any increase in the height and extent of the whole amount of land on the globe must be attended with a corresponding depression of the sea-bottoms, and therefore an actual subsidence of the sea-level everywhere. Hence, if it be true, as is generally believed, that the continents have been, on the whole, increasing in extent and in height, in the course of geological history, then it is true also that the seas have been subsiding, and that therefore the relative changes are the sum of these two.

Admitting, however, that the actual increase of land at the *present time* is imperceptible, or at least very small in comparison with the oscillatory movements described above, we may look upon the *sea-level as fixed;* this statement being sufficiently correct when regarding the subject from the physical point of view, though untenable when regarded from the geological point of view. Admitting, then, the fixedness of the sea-level, what are the causes of the gradual movements of the solid crust?

Babbage's Theory.—Babbage believed that, in the vicinity of volcanoes, the rise and fall of ground were due to the expansion and contraction of rocks by heating and cooling. The reëlevation of the temple of Serapis occurred apparently soon after the eruption which formed Monte Nuovo (Fig. 109). It is not improbable that this reëlevation was the result of the heating and vertical expansion of the rocks to great depth, caused by the eruption of the interior heat at this point. A very small elevation of temperature of rocks several miles thick would be sufficient to produce a vertical expansion of twenty feet.

Other cases, such as the rise of sea-margins at a distance from volcanic action, Babbage explains as follows: Large accumulations of sediments, such as occur generally on coasts, would cause a rise toward the surface of all the subjacent isogeotherms. This increase of temperature of the crust would cause a vertical elongation or swelling of the crust at that point, and a consequent rise above the sea-level.

The great objection to this theory, as applied to these latter cases, is, that the places where the greatest quantities of sediments are depositing (as, for instance, the deltas of great rivers) are places of *subsidence*, instead of elevation.

Herschel's Theory.[1]—Sir John Herschel assumes, as a general law—what has been proved in a great number of instances—that areas of great accumulation of sediment are areas of subsidence. He agrees with Babbage, that accumulation of sediments must cause an upward movement of the isogeotherms, but he differs from Babbage in believing that this invasion of sediments by the interior heat would produce *subsidence* instead of elevation. For, according to Herschel, the invasion of sediments by the interior heat would produce chemical changes, and sometimes even aqueo-igneous fusion. These chemical changes, whatever other effects they produce, would certainly change sediments into crystalline rocks (metamorphism). The accumulating sediment meanwhile would subside, by the pressure of its own weight, on the liquid or semi-liquid thus formed.

General Theory.—The theory of Babbage accounts with great probability for the rise of ground in the vicinity of volcanoes, and Herschel's theory accounts, perhaps, for the subsidence of deltas and other places where great accumulation of sediments occurs; and this latter theory has the additional advantage of accounting for metamorphism, and perhaps, also, for volcanic phenomena. But it is evident that some other and more general theory is necessary to account for those great inequalities of the earth's crust which form land and sea-bottom. The formation of these must be a phenomenon somewhat different from those local oscillations which alone have been the subject of direct observation. Such general changes can only be the result of gradual unequal *contraction of the whole earth* consequent upon its secular cooling. The full discussion of this theory, however, belongs properly to the second part of this work.

[1] Herschel, "Proceedings of the Geological Society," vol. ii., p. 548, and Babbage, ibid., p. 72.

CHAPTER IV.

ORGANIC AGENCIES.

As agents modifying the crust of the earth, *organisms* are, perhaps, inferior to the agents already mentioned (although the immense thickness and extent of limestone strata are a monument of their power in this respect); nevertheless, they are peculiarly interesting to the geologist as delicate indicators of climate, and recorders of the events of the earth's history. We will take up the subject of their agency under four heads, each having a separate application in interpreting the structure and history of the earth, viz.: 1. Vegetable Accumulations, to account for coal; 2. Bog-iron Ore, to account for iron-ores inclosed in the strata; 3. Lime Accumulations, to account for limestones, etc.; 4. Geographical Distribution of Organisms, to explain their distribution in former epochs.

SECTION 1.—VEGETABLE ACCUMULATIONS.

Peat-Bogs and Peat-Swamps.

Description.—In humid climates, in certain places, badly drained and overgrown with moss and shrubs, a black carbonaceous mud accumulates often to great depths. This substance is called peat or turf, and such localities peat-bogs. The thick mass of vegetation which covers their surface, with its interlaced roots often forms a crust, upon which a precarious footing may be found, but beneath this is a tremulous, semi-fluid quagmire, sometimes twenty to forty feet deep, in which men and animals, venturing in search of food, are often lost. These bogs are most numerous in northern climates. One-tenth of the whole surface of Ireland, and large portions of Scotland, England, and France, are covered with peat. The bog of the Shannon River is fifty miles long and three miles wide; that of the Loire in France is 150 miles in circumference. Extensive bogs exist also in the northern portions of our own country. The amount of peat in Massachusetts alone has been estimated at more than 15,000,000,000 cubic feet (Dana). In California, an imperfect peat covers large areas about the mouth of the San Joaquin River and elsewhere (tule-lands). In more southern climates, where the condition of humidity is present, immense accumulations of peat also occur—not, however, in bogs overgrown with moss and shrubs, but in extensive *swamps* covered with *large trees*.

Composition and Properties of Peat.—Peat is disintegrated and

partially decomposed vegetable matter. It is composed of carbon, with small and variable quantities of hydrogen, oxygen, and nitrogen. It is, therefore, vegetable matter which has lost a part of its gaseous constituents, and in which, therefore, the carbon is greatly in excess. In more recent peat, the vegetable nature and structure are plainly detectable by the eye, but in older peat only by the microscope. In all countries where it occurs, it is dried and used as a valuable domestic fuel. By powerful pressure it may be converted into a substance scarcely distinguishable from some varieties of coal, and, thus changed, is now extensively used for all purposes for which coal is used, and has therefore become an important article of commerce.

Peat possesses a remarkable *antiseptic property*. This property is probably due to the presence of humic acid and of hydrocarbons analogous to bitumen, which are formed only when vegetable matter is decomposed in presence of *excess of water*. The bodies of men and animals have been found in bogs in a good state of preservation, which must have been buried many hundred years. In 1747, in an English bog, the body of a woman was found, with skin, nails, and hair, almost perfect, and *with sandals on her feet*. In Ireland, under eleven feet of peat, the body of a man was found *clothed in coarse hair-cloth*. Several other instances of bodies of men and animals, and innumerable instances of skeletons of animals, preserved in bogs where they have perished, might be mentioned. Large trunks of trees are often so perfectly preserved that they are used as timber, and stumps similarly preserved are found with their roots firmly fixed in the under-soil of the bog as if they had grown on the original soil on which the bog was accumulated.

Mode of Growth.—Plants take the greater portion of their food from the air, and give it, by the annual fall of leaf and finally by their own death, to the soil. Thus is formed the humus or *vegetable mould* found in all forests. This substance would increase without limit, were it not that its decay goes on *pari passu* with its formation. But in peat bogs and swamps the excess of water, and, still more, the antiseptic property of the peat itself, prevent complete decay. Thus each generation takes from the air and adds to the soil continually and without limit. The soil which is made up entirely of this ancestral accumulation continues to rise higher and higher, until the bog often becomes higher than the surrounding country, and, when swollen by unusual rains, bursts and floods the country with black mud. A bog is therefore composed of the vegetable matter of thousands of generations of plants. It represents so much matter withdrawn from the atmosphere and added to the soil. In some cases, besides the material deposited from the growth of vegetation *in situ*, the accumulation may be partly also the result of organic matter drifted from the surrounding surface-soil.

Rate of Growth.—The rate of peat-growth must be very variable, since it depends upon the vigor of the vegetation and upon the manner of accumulation, whether entirely by growth of plants *in situ*, or partly by driftage. Many of the European bogs are evidently the growth of not more than eighteen hundred years, for they were forests in the time of the Romans, or even later. The felling of these forests, as a military measure to complete the subjugation of the country, and the consequent impediments to drainage thus produced, have changed them into bogs. At their bottoms, and covered with eight to ten feet of peat, are found the trunks and the stumps of the original forests, the axes and coins of the Roman soldiers, and the roads of the Roman army. The rate of accumulation has been variously estimated, from one or two inches to several feet per century. In all cases of simple growth *in situ*, however, and therefore always in great peat-swamps, the increase is very slow.

Conditions of Growth.—The conditions usually considered necessary for the formation of peat are *cold* and *moisture;* and of these the former is considered the more important, as without cold it is supposed vegetable matter would be destroyed by decay. In proof of this it is stated that peat-bogs are more numerous in cold climates. But it is more probable that excess of moisture is the only important condition. This condition may be rarer in warm climates on account of the greater capacity of the air for moisture in these climates; but when it is present, immense accumulations of peat occur in extensive swamps. The *Great Dismal Swamp* is a good illustration. This swamp, situated partly in North Carolina and partly in Virginia, is forty miles long by twenty-five miles wide. It is covered with a dense forest of cypress and other swamp trees, by the annual fall of whose leaves the peat is formed. These trees, by means of their long tap-roots and their wide-spreading lateral roots, maintain a footing in the insecure soil, but are

FIG. 112.

often overthrown, and add their trunks and branches to the vegetable accumulation. The original soil, upon which the accumulation was formed, must have been lower in the centre, but the surface of the peat rises very gently toward the centre, which is twelve feet higher than the circumference (Fig. 112). Near the centre there is a lake of clear, wine-colored water, seven miles across and fifteen feet deep, the banks and bottom of which are composed of pure peat.

In the Mississippi River swamps there are also large areas where pure peat has been accumulating for ages, and is still accumulating, by growth of trees *in situ*, though subject to the annual floods of the river.

The *pureness* of the peat in these cases is due to the fact that the muddy waters of the river are strained of all their sedimentary matter by passing through the dense jungle-growth of cane and herbage which surrounds these favored spots. Thus only pure water reaches them.[1] Similar peat-swamps are found at the mouths of the Ganges, the Niger, and other great rivers.

Alternation of Peat with Sediments.—We have already stated (page 129) that a section of the delta-deposit of many great rivers, such as the Mississippi, Ganges, and Po, reveals alternate layers of fresh-water and marine sediments, with thin layers of vegetable mould containing stumps. In some cases these layers of vegetable mould amount to considerable thickness of turf or peat. Layers of peat two feet thick have been found between layers of river-mud in the delta of the Ganges (Lyell's "Principles of Geology"). Similar layers have been found in the delta of the Po. They are evidently *submerged peat-swamps.* These facts are of great importance in the explanation of the accumulation of coal.

Drift-Timber.

Great rivers in wooded countries always bring down in large numbers the trunks of trees torn from the soil of their banks. These trunks lodging near their mouths, where the current is less swift, and accumulating from year to year, form *rafts* of great extent. The great raft of the Atchafalaya, which was removed in 1835 by the State of Louisiana, was a mass of timber ten miles long, seven hundred feet wide, and eight feet thick. It had been accumulating for more than fifty years, and at the time of its removal was covered with vegetation, and even with trees sixty feet high. Similar accumulations of drift-wood are described as occurring in the Red River, the Mackenzie River, and in Slave Lake. Such rafts become finally imbedded in river-mud, and undergo a slow change into lignite or imperfect coal. Beds of partially-formed lignite are therefore found in sections of the delta-deposit of almost all great rivers. We will use these facts in speaking of the theories of the coal.

Section 2.—Bog-Iron Ore.

At the bottom of peat-bogs is often found a "*hard pan*" of iron-ore, sometimes one to two feet thick. The same material often collects in low spots, even when there is no decided bog. The manner in which this iron-ore accumulates is very interesting, and in a geological point of view very important.

Peroxide of iron exists very generally diffused as the red coloring-matter of soils and rocks. In this form, however, it is insoluble, and therefore cannot be washed out by percolating waters. For this pur-

[1] Lyell's "Elements of Geology," fifth edition, p. 385.

pose the agency of decomposing organic matter, present in all percolating waters, is necessary. Decomposition of organic matter is a process of oxidation. In contact with peroxide of iron (ferric oxide) it deoxidizes, and reduces it to *protoxide* (ferrous oxide). The acids, especially carbonic acid, produced by decomposition of the organic matter, then unite with the protoxide, forming carbonate of iron. The carbonate, being soluble in water containing excess of carbonic acid, is washed out, leaving the soils or rocks decolorized, and the iron-charged waters come up as chalybeate springs. But the ferrous carbonate rapidly oxidizes again in the presence of air, by exchanging its carbonic acid for oxygen, and returns to its former condition of ferric oxide, and is deposited. Thus all about iron-springs, and in the course of the streams which flow from them, and in low places where their waters accumulate, we find reddish deposits of *ferric oxide.* This is the most common but not the only form. For if the iron-waters accumulate, and the iron be deposited in the presence of excess of organic matter, as peat, then the iron is not (for in the presence of this reducing agent it cannot be) reoxidized, but remains in the form of *ferrous carbonate.*

Thus there are two forms in which iron leached out from the soils and rocks may accumulate, viz., ferric oxide and ferrous carbonate: the former is accumulated where the organic matter is in small quantities, and consumes itself in doing the work of dissolving and carrying; the latter where the organic matter is in excess.

Many familiar phenomena may be explained by the principles given above: 1. Clay containing both iron and organic matter is never red, but always blue or slate-colored, because the iron is in the form of ferrous carbonate; but the same clay will make good red brick, because by burning the organic matter is destroyed and the iron peroxidized. 2. In *red-clay* soils, such as those of our primary regions, the surface-soil, especially in forests, is always decolorized, the coloring of peroxide of iron being washed out and carried deeper by water containing organic matter derived from the vegetable mould. 3. In sections of red clay, as the sides of gullies or railroad-cuttings, along every fissure or crevice through which superficial waters percolate, the clay is bleached. The marbled appearance of red clays is also probably due, in a great measure, to the irregular percolation of superficial waters containing organic matter. 4. The under clay or sand of peat-bogs is usually decolorized.

We will hereafter make use of these facts and principles in the explanation of beds of iron-ore.

SECTION 3.—LIME ACCUMULATIONS.

Coral Reefs and Islands.

Interest and Importance.—The subject of corals and coral reefs is one of much popular as well as scientific interest. The strange forms and often splendid colors of the living animals; the number and extreme beauty of the coral islands which gem the surface of certain seas; the large amount of habitable land which owes its existence to the agency of these minute animals; the fact that a large area, probably several thousand square miles, has been thus added to our own territory; the great dangers connected with the navigation of coral seas, strikingly displayed on our own coast by the fact that the considerable town of Key West is almost wholly dependent on the wrecking business for its existence—these and many other facts invest the subject with popular interest, while the great importance of corals as a geological agent gives the subject a scientific interest no less strong.

Coral Polyp.—The animal which secretes coralline stone is no insect, as generally supposed, but belongs to one of the lowest divisions of the animal kingdom, viz., the class of polyps. Like most of the lowest animals, it is composed of soft, gelatinous, and almost transparent tissue. The animal, however, has the power of extracting carbonate of lime from sea-water, and depositing it within its own body. The lime carbonate is deposited only in the lower portion of the animal, leaving thus the upper part and the tentacles free to move. The radiated structure of the polyp is perfectly reproduced in the coralline axis. This is a purely vital function, having no more connection with volition than the secretion of the shell of an oyster or the bones of the higher animals. The limestone thus deposited within the animal constitutes 90 to 95 per cent. of its whole weight.

Compound Coral, or Corallum.—A single coral polyp is very small, but, like many of the lower animals, it has the power of multiplying indefinitely by buds and branches. Thus are formed compound corals. These may branch profusely, and then may be called *coral-trees;* or may grow in hemispherical masses, and are then called *coral-heads.* Coral-trees are sometimes six or eight feet high, and coral-heads fifteen to twenty feet in diameter. They consist of millions of individual coral polyps. Only the upper and outer portions of a coral-tree, and outer portion of a coral-head, are living; the lower and interior portions consist only of coralline limestone without life.

Coral Forests.—Coral polyps, however, reproduce not only by budding, but also by eggs. These eggs have the power of locomotion. As soon as they are extruded, they swim and float away, and, if they fall on sea-bottom favorable for their growth, they soon form first a

coral polyp, and finally a coral-tree or coral-head. Thus from one coral-tree other coral-trees spring up all around and form a *coral forest*, which spreads in every direction where they find conditions favorable.

Coral Reef.—Finally, the limestone accumulation of thousands and millions of coral forests growing and dying on the same spot, together with the shells of mollusks and the bones of fishes which live in swarms preying on the corals, the whole, of course, crowned with the living forest of the present generation, constitute the *coral reef*. It is evident, then, that a reef is formed somewhat after the manner of a peat-bog. As a peat-bog represents so much matter taken from the air, so a coral reef represents so much matter taken from the sea-water. As each generation adds itself to the ancestral funeral-pile, the ground upon which the corals grow steadily rises until it becomes elevated far above the surrounding sea-bottom.

Coral Islands.—These are due to the action of waves upon the coral reefs. We have already seen how low islands are formed on submarine banks by this agency. Now, reefs are also a kind of submarine

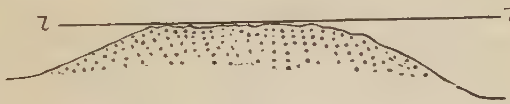


FIG. 113

bank. On these, therefore, islands are also formed by waves. Fig. 113 represents an ideal section across a reef, as it would be if no wave-action interfered, *l l* being the sea-level. But by the action of the beating waves during storms large masses of reef-rock, often six or eight feet in diameter, or great coral-heads, are broken off from the outer or

FIG. 114.

seaward side of the reef and rolled over to the leeward side. These form a nucleus about which collect similar or smaller fragments, and among these still smaller fragments, and these again are filled in and made firm with coral-sand, and the whole cemented into solid limestone rock (breccia) by the carbonate of lime in the sea-water.

Islands thus formed, like all wave-formed islands, are low (twelve to fifteen feet high) and narrow (one-quarter to one-half mile wide), but long in the direction of the reef. They are at first perfectly bare, but

become in time covered with vegetation, and even teeming with population. They are celebrated for their gem-like beauty. The final result is shown in ideal section in Fig. 114, in which the dotted portion is reef-rock, the strong waving line the surface of the living reef, and the shaded portion the island.

Conditions of Coral-Growth.—Reef-building corals do not grow in all seas, nor over the whole bottom of the sea indiscriminately, but are confined to certain seas, and in these to certain spots and lines. The conditions of their growth are:

1. *A Winter-Temperature of* 68°.—This condition confines them almost entirely to the torrid zone. The most marked exception to this is on the Florida coast and the Bahamas, where corals extend to 28° north latitude, and in the Bermudas to 32° north latitude. This extension of the usual limits of reef-building corals is due to the warm tropical waters carried northward by the Gulf Stream.

2. *A Depth of not more than One Hundred Feet.*—This condition confines them to submarine banks, and especially to the shores of continents and islands.

3. *Clearness and Saltness of the Water.*—On account of this condition corals will not grow on muddy shores, nor off the mouths of rivers, being destroyed by the fresh and muddy water.

4. *Free Exposure to Waves.*—Some species of corals grow in still water, but the strongest reef-building species delight in the dash of the surf. They will even flourish and build an almost perpendicular wall in breakers which would wear away the hardest rock. The reason is, that the immense profusion of life on a reef rapidly exhausts the water of the oxygen necessary for respiration, and of the carbonate of lime necessary for their stony structure, and therefore constant change of water is necessary.

All the conditions mentioned above apply only to reef-building species. Some corals live in temperate regions, some in very deep water, and some in sheltered places.

Pacific Reefs.—The reefs of the Pacific Ocean are of three general kinds, viz., *fringing reefs*, *barrier reefs*, and *circular reefs* or *atolls.* We will describe these in the order mentioned.

Fringing Reefs.—In the tropical Pacific every *high* island or previously-existing land of any kind is surrounded by a reef which attaches itself to the shore-line, and extends outward on every side just beneath the water-level, as far as the condition of depth will allow, thus forming a submarine platform bordering the island or other land. At the outer margin of this platform the bottom drops off very suddenly, forming a slope of 50° to 60°, and sometimes almost perpendicularly. The position and extent of the coral platform is indicated to the eye of the observer by a white sheet of breakers which surrounds the island like

a snowy girdle, and extends some distance from the shore-line (Fig. 115.) The section Fig. 116 will give a clear idea of the contour of land and sea bottom. In this and the following sections the dotted parts represent coral formation. If the island is large, and considerable

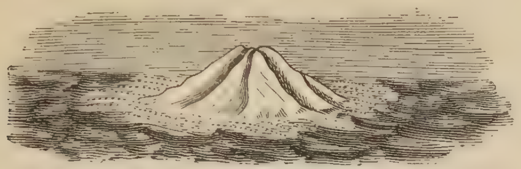


Fig. 115.

rivers flow into the sea, breaks in the reef platform will occur opposite the mouths of the rivers, the corals in these places being destroyed by the fresh, muddy waters. In the case of fringing reefs no islands are

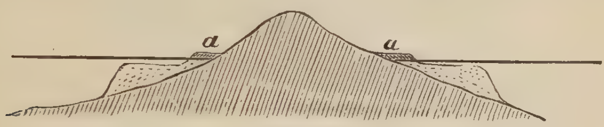


Fig 116.

formed by the action of waves, but only a shore-addition to the original island, as shown at *a a* in the section.

Barrier Reefs.—In many cases besides the fringing reef there is another reef surrounding the island like a submarine rampart at the distance of from ten to fifty miles. As the reef rises nearly to the surface of the sea, its position is indicated by a snowy girdle of breakers surrounding the island at a distance, and this snowy girdle is gemmed with wave-

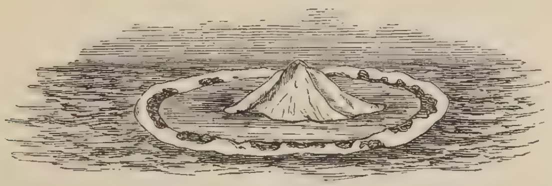


Fig. 117.

formed green islets. Within this girdle, and between the rampart and the island, there is a ship-channel twenty or thirty fathoms deep (Fig. 117). Through breaks in the coral rampart ships enter this channel and find secure harbor in a stormy sea. The section Fig. 118 will give a clear idea of the conformation of bottom. On the landward side of the

coral rampart the slope of the bottom is gentle, but on the seaward side it is very steep, so that it is almost unfathomable at a short distance from the reef.

FIG. 118.

Circular Reefs, or Atolls.—These are the most wonderful of the reefs of the Pacific. In a circular reef there is no volcanic island or

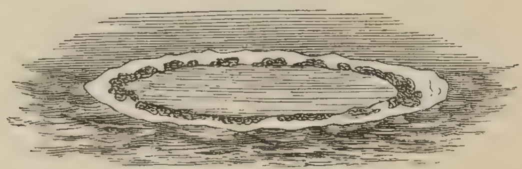


FIG. 119.

other visible land to which the reef is attached. Imagine a circular line of breakers like a snow-wreath on the sea, indicating a circular

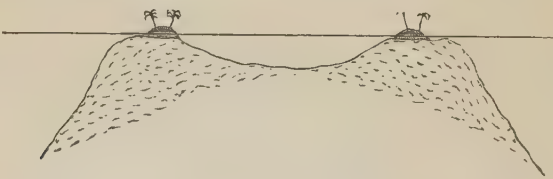


FIG. 120.

submarine ridge (the coral reef) gemmed as before with wave-formed

FIG. 121.—View of Whitsunday Island.

islets; and within the circle a lagoon of placid water twenty or thirty fathoms deep (Fig. 119). It is a submarine urn standing in unfathomable water, as seen in the section Fig. 120. Through breaks in the reef ships enter the charmed circle and find safe harbor. By means of sounding it is found that on the interior or lagoon side the slope of the bottom is very gentle, but on the outer or seaward side is very steep, often 50° to 60°, and sometimes in places almost perpendicular to almost unfathomable depth. Fig. 121 gives a perspective view, and Fig. 122, *a*, a map view, of an atoll, showing their regular circular form of the reef and the little islands which gem its surface.

Small Atolls and Lagoonless Islands.—Besides the atolls already described, there are others, evidently of similar origin, but much smaller, in which the land is continuous. Sometimes the continuous line is open on one side (Fig. 122, *b*), and the lagoon is still in connection with the open sea. Sometimes the circle of land is complete, and the lagoon is isolated from the sea (Fig. 122, *c*). Sometimes the lagoon closes up, and a lagoonless island is the result (Fig. 122, *d*). These different forms graduate into one another and into the typical atoll.

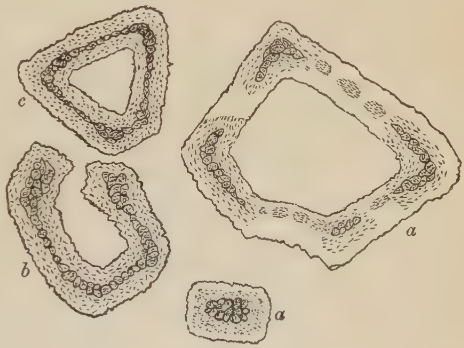


FIG. 122.

Theories of Barrier and Circular Reefs.

Fringing reefs require no theory. Corals attach themselves to the shore-line because they find there the depth necessary for their growth, and they extend outward until they are limited by the increasing depth. But there is a real difficulty in explaining barriers, for they seem to rise from water too deep for coral-growth; and the difficulty becomes still greater in the case of circular reefs or atolls, for these seem to have no connection with any preëxisting land, but seem to grow up from an unfathomable bottom. These latter, by their singularity and extreme beauty, have always attracted the attention and excited the wonder of Pacific travelers; and to their explanation theories have been principally addressed.

Crater Theory.—This theory supposes that an atoll is an extinct submarine volcano, the lagoon being the crater and the reef the lip or margin of the crater; that corals, finding on this circular rim the conditions of depth necessary for their growth, occupy and build upon it to

the surface of the water, after which, of course, waves finish the work by beating up the islets. The incredible supposition that thousands of these volcanoes should have come within 100 feet of the surface, and yet none of them appear above the surface, is not necessary; for we may suppose that many of them were originally above the surface, but, being composed of ashes and cinders, have been washed down by the waves. In 1831 a volcano burst forth in the Mediterranean and quickly formed an island of cinders and ashes, called Graham's Island. In a few months this island was entirely washed away by the waves, and only a circular submarine bank remained. If corals grew in the Mediterranean, there seems no reason why a circular reef should not have been formed.

Objections.—Even in its most plausible form, however, this theory is very improbable as a general explanation of atolls. 1. The great size of some of these atolls—thirty, sixty, and even ninety miles in diameter; and, 2. The high angle of the slope of these submarine mountains—50° to 60° or more—seem inconsistent with their volcanic origin. 3. This theory offers no explanation of the barrier reefs, and yet it is possible to trace every stage of gradation between barriers and atolls, showing that they are due to similar causes.

Subsidence Theory.—There can be little doubt that this is the true theory. It explains not only atolls, but also barriers, and connects both in a satisfactory manner with fringing reefs. It supposes that the sea-bottom, where atolls and barriers occur, has been for ages subsiding, but at a rate not greater than the upward building of the coral-ground; that every reef commences as a fringing reef, but, in the progress of subsidence, was converted first into a barrier and finally into an atoll. For, as the volcanic island went down, the corals would build upward on the same spot; and as the island would become smaller and smaller, and the corals would grow fastest on the outer side of the reef, where they are exposed to the breakers, it is evident that the reef would become separated from the island by a ship-channel, and thus become a barrier. Finally, when the island disappears entirely, the reef, still building upward, would become an atoll. These changes are represented in the accompanying section (Fig. 123). As the changes are relative, they may be represented either by the land sinking or the sea-level rising; for the sake of convenience we use the latter. In the figure, $l'' \; l''$ represents the sea-level when the reef was a *fringe*, $l' \; l'$ when it was a *barrier*, and $l \; l$ the present sea-level, when it has become an atoll. The ship-channel and the lagoon, though always lower, rise *pari passu* with the reef proper. This is the result partly of the growth of placid-water species of corals, and partly of the drifting of coral *débris* from the reef, and detritus from the volcanic island. It is seen that the corals do not build a vertical wall, and therefore that the atoll is always

smaller than the coast-line of the original island. Consequently, if the subsidence continues, a typical atoll is changed into a small closed lagoon, and, finally, into a lagoonless island. These, therefore, indicate the deepest subsidence.

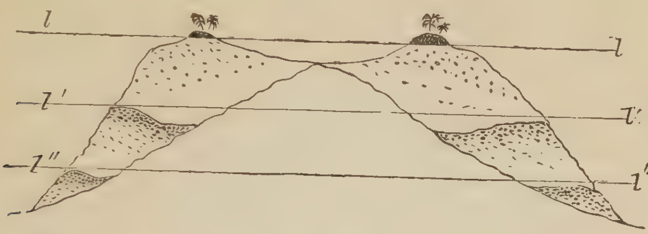


FIG. 123.

Proofs.—1. This theory accounts for all the more obvious phenomena of atolls, such as their irregular circular form, their size, the steepness of their outer slopes, etc. 2. Every stage of gradation between the fringing reef on the one hand, and the atoll on the other, has been traced by Dana, showing that they are all different stages of development of the same thing. We have in the Pacific some high islands, which are surrounded by a pure fringing reef; others in which the reef is a fringe on one side and a barrier on the other; others in which the barrier is one mile, two miles, five miles, ten miles, twenty, or thirty miles distant; others which are called atolls, but the point of the original volcanic island is still visible in the middle of the lagoon; others which are perfect atolls, but, by sounding, the head of drowned volcanic island is still detectible. The next step in the series is the perfect atoll, then the small atoll, and, finally, the lagoonless coral island. These last kinds show that the original island has gone down deeply. 3. By grappling-hooks *dead* coral-trees have been broken off and brought up from the ground where they once grew, now far below the limiting depth of coral-growth. The evidence of subsidence in this case is of the same kind and force as that derived from submerged forest-ground (page 129). The corals have been carried below their depth and drowned. 4. The remarkable distribution of the various kinds of reefs brought to light by Dana is satisfactorily explained by this theory, and therefore is an argument in its favor. In the middle of the atoll region of the Pacific there is a *blank area*, 2,000 miles long and 1,000 or more miles wide, where there are no islands. Next about this is an area in which *small atolls* predominate; about this again the region of ordinary atolls; beyond this the region mostly of barriers, and finally of fringes. Now, by this theory this distribution is thus explained: The sea-bottom in the blank area has gone down so fast that the corals have not been able to keep pace, and have therefore been drowned, and left no monu-

ment of their existence. In the next region the corals have been able to keep within living distance of the surface, but the original islands have not only disappeared, but gone down to great depths. In the next the original high islands have disappeared, but not gone down so deep; in the next they have sunk only to the middle. The fringing reefs stand on the margin of the sinking area. Outside of this again there is in some places even evidence of upheaval instead of subsidence. Raised beaches in the form of fringing-reef rocks are found clinging to the sides of high islands many feet above the present sea-level. 5. In some places this subsidence seems to be still in progress. On certain coral islands sacred structures of stone made by the natives are now standing in water, and the paths worn by the feet of devotees are now passages for canoes (Dana).

It may be regarded as certain, therefore, that every atoll marks the site of a sunken volcanic island.

Area of Land lost.—Probably several hundred thousand square miles of habitable high land has been lost by this subsidence. The actual extent of atolls known is at least 50,000 square miles. But this is far less than the loss of high land. For—1. It is certain that the area of an atoll is always less than that of the original fringe or base of the original high island, for the outer wall of an atoll is not perpendicular. The contraction continues as the subsidence progresses, until small atolls or only lagoonless islands remain. 2. An immense lost area is represented by the space between *barriers* and their high islands. The great Australian barrier extends along that coast 1,100 miles, at an average distance of thirty miles, with a ship-channel between of thirty to sixty fathoms deep. This single barrier, therefore, represents a lost land-area of 33,000 square miles. 3. In the blank area already spoken of, probably many islands went down, and left no record behind.

The large amount of high land thus lost has been replaced only to a small extent by the wave-formed coral islets on the reefs.

Amount of Vertical Subsidence.—The amount of subsidence may be estimated by the distance of barriers from their high islands, or by

Fig. 124.

soundings off the reefs, to ascertain the height of these coral mounds, or by the average height of the high islands of the Pacific. 1. The average slope of the high islands of the Pacific is about 8°. Now, assuming this slope (Fig. 124), a barrier, *d*, at the distance of five miles

would be 3,700 feet thick, and would represent a subsidence nearly to that extent (Rad. : tan. 8° :: $a\ d : d\ b$); a distance of ten miles would represent a vertical subsidence of 7,400 feet. Many barriers are at much greater distance. 2. Off Keeling atoll 6,600 feet, a line of 7,200 feet found no bottom (Darwin). Near other atolls a depth of 3,000 feet has been found (Dana). 3. The average height of the high islands of the Pacific cannot be less than 9,000 feet (Dana); some of them reach nearly 14,000 feet. It is very improbable that among the hundreds of atolls known, not one of their high islands should have reached the average elevation of 9,000 feet. Yet these have entirely disappeared, and not only so, but the small atolls and lagoonless islands, and more especially the blank area, would seem to indicate that they have disappeared to great depths. For these reasons, it is almost certain that the extreme subsidence has been at least 9,000 feet. We will take 10,000 feet as the most probable extreme subsidence.

Rate of Subsidence.—The rate of subsidence may have been to any degree less, but cannot have been greater, than the rate of coral *ground-rising;* for otherwise the corals would have been carried below their depth and drowned. It is difficult to estimate the rate of coral ground-rising, but the only basis of such estimate is the rate of coral-growth. Of the observations on this point we select two, one of them on the head-coral (meandrina), the other on the staghorn-coral (madrepore):

1. On the walls of the fort at the Tortugas, Florida, meandrina commenced to grow, and in fourteen years the crust had become only one inch thick. Agassiz takes one inch in eight years as a probable rate under favorable circumstances. This would be one foot in a century. As this is a head-coral, the coral-growth may be taken as the measure of the reef ground-rising.

2. In examining the reefs about the Tortugas in the winter of 1851, an extensive grove of madrepore was found in the comparatively still water on the inside of the outer reef, in which the thick-set prongs had grown, year after year, to the same level, and were successively killed. The mean level of the water here is lower during the winter, by about a foot, than during the summer. The falling of the water annually *clips* this grove at the same level. Now all the prongs at this level were dead for about three inches. Evidently, therefore, this is the annual growth of madrepore-prongs.[1] But in branching corals the rate of point-growth is very different from the rate of ground-rising. If all the points of a madrepore be cut off three inches, then ground into powder, and the powder strewed evenly over the ground shaded by the coral-tree, the elevation thus produced would correctly represent the annual rate of reef ground-rising for this species. A quarter of an

[1] *See* full account of these observations in *American Journal of Science and Arts*, vol. x., p. 34.

inch would probably be a full estimate. This would make two feet for a century. One foot to two feet per century is, therefore, probably about the rate at which coral ground rises. As already stated, the rate of subsidence may be less, but cannot be greater, than this.

Time involved.—At this rate 10,000 feet of vertical subsidence would require 500,000 to 1,000,000 years. How much of this belongs to the present geological epoch, it is impossible to say. Dead corals, identical with those still living on the reefs, have been brought up from a depth of 250 feet, but, as this is only 150 feet below the limit of coral-growth, it would require only 75 to 150 centuries. The process probably commenced in previous geological epochs, and has continued to the present time. This is, therefore, an admirable example of geological agencies still at work.

Geological Application.—The facts brought out in the preceding pages are of great importance in geology.

1. We have here the most magnificent example of subsidence still in progress. The subsiding area has not been accurately defined, but it probably covers nearly the whole of the intertropical Pacific. According to Dana, estimated by the atolls alone, it is 6,000 miles long and 2,000 miles wide; but if we take into account also *barriers*, which are equally certain evidences of subsidence, it extends east and west from the extreme of the Paumotu group on the one side to the Pelews on the other, and north and south from the Hawaiian group to the Feejees, making an area of not less than 20,000,000 square miles. Now, it is evident that there must have been, as a correlative of this extensive and *permanent* downward movement, an equally extensive permanent elevation of the earth's crust somewhere else. Dana thinks its correlative is found in the extensive elevations of the Glacial epoch, and therefore that the whole work was accomplished *since the Tertiary*. But it is more probable that its correlative is found in the gradual bodily upheaval of the whole western side of the continent, especially in the Rocky Mountain region, which commenced after the Cretaceous.

2. We have here the formation of limestone rocks of various kinds going on before our eyes over immense areas and several thousand feet in thickness, and we learn thus that limestones are of organic origin.

3. The character of the rocks thus formed is very interesting to the geologist. In some places, as we have already seen, it is a coarse conglomerate, or *breccia*, composed of fragments of all sizes cemented together; in some places it is made up entirely of rounded granules of coralline limestone (*coral-sand*), cemented together, and forming a peculiar oölitic rock (ωον λιθος, *egg-stone*). But the larger portion of the reef ground is a fine compact limestone, made up of comminuted coralline matter (*coral mud*), cemented together. This fine coral mud is carried by waves and tides into the lagoon, and serves to raise its

bottom: it is also carried by currents and distributed widely over the neighboring sea-bottoms. Soundings in coral seas bring up everywhere this fine coral mud, showing that compact limestone is now forming over wide areas in coral seas. The reef-rock, as already stated, has been found clinging to the sides of high islands, having been elevated many feet above sea-level; in other cases atolls have been elevated 250 feet above the sea-level. The structure of the reef-rock has thus been exposed to view. In some places it contains imbedded remains of corals and shells, but in other parts it is entirely destitute of these remains.

Reefs of Florida.

The reefs of Florida deserve a brief separate notice, both because they are different from those of the Pacific, having been formed under different conditions, and because they are much more efficient agents in *land-making*, and illustrate in a striking manner how different agencies coöperate for this purpose. The process has been accurately observed.

Description of Florida.—Fig. 125 is a *map* of Florida, with its reefs and keys, and Fig. 126 is a *section* along the line *p p*. The southern coast (*a a*) is ridge, elevated twelve to fifteen feet above the sea-level, within which is the Everglades (*e*), an extensive fresh-water swamp only two or three feet above sea-level, and dotted over with small islands, called *hummocks*. Between the southern coast (*a a*) and

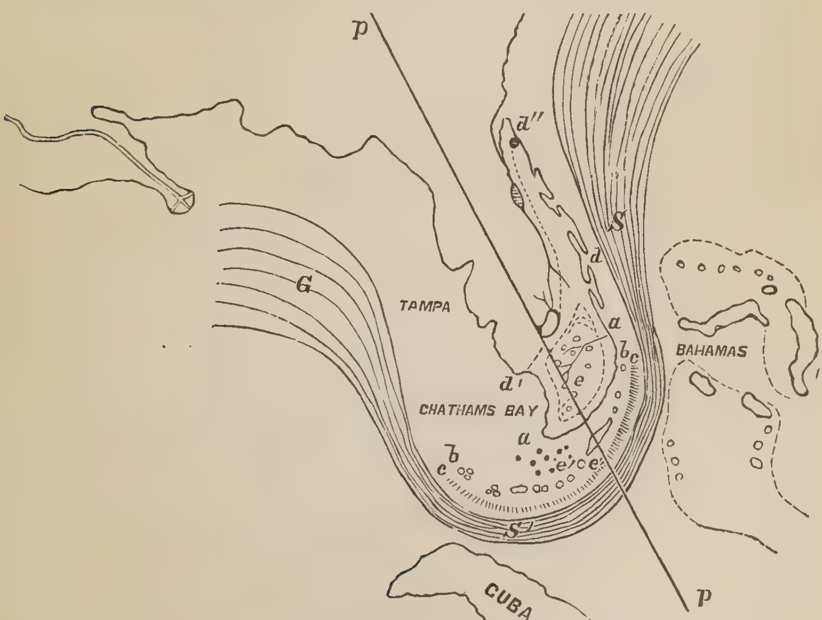


Fig. 125.—Gulf Stream and the Reefs and Keys of Florida.

the line of keys (b b) the water (e') is very shallow, only navigable to smallest fishing-craft, and dotted over with small low mangrove islands. A considerable portion of this area, in fact, forms mud-flats at low tide. Between the line of keys (b b) and the living reef (c c) there is a ship-channel (e'') five to six fathoms deep. Outside the reef (c c) the bottom slopes rapidly into the almost unfathomable abyss of the Gulf Stream (G S S).

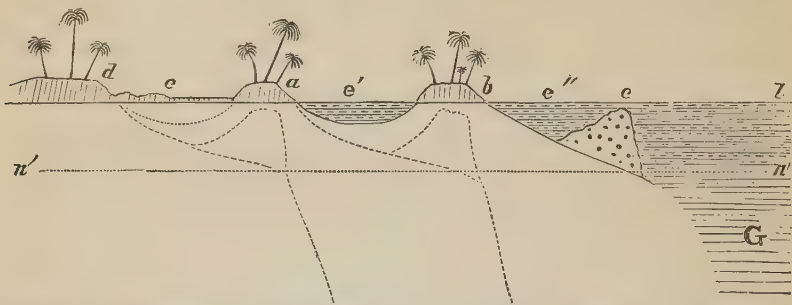


FIG. 126.—In both figures a = Southern coast; b, Keys; c, Reef; e, Everglades; e', Shoal water; e'', Ship-channel; G S S, Gulf Stream.

General Process of Formation.—Now, Agassiz[1] has proved that not only the living reef but the keys, the southern coast, and the peninsula, certainly as far north as the north shore of the Everglades (d d), and probably on the east side as far north as St. Augustine (d'), have been formed by coral agency. The evidence of this important conclusion is that the rock in all these parts is identical with the reef-rock already described, and with what is even now forming under our eyes on the living reef (c c). It is, moreover, almost certain that the peninsula of Florida has been progressively elongated by the formation of successive barrier reefs, one outside of the other, from the north toward the south, and the successive filling up of the intervening ship-channels, probably by coral *débris* from the reef and sediments from the mainland.

History of Changes.—The history of changes was as follows: There was a time when the north shore of the Everglades (d d') was the southern limit of the peninsula. At that time the ridge (a a) which now forms the south shore was a reef. Upon this reef by the action of waves was gradually formed a line of coral islands, which finally coalesced into a continuous line of land, and by the filling up of the intervening ship-channel was added to the peninsula, the ship-channel being converted into the present Everglades. In the mean time another reef was formed in the position of the present line of keys. This has already been converted into a line of wave-formed islands, and its ship-channel into shoal water and mud-flats. Eventually the peninsula will be extended to the line of keys, and the shoal water (e') will become another Everglades and the mangrove islands its hummocks. Already another reef has

[1] "Coast Survey Report" for 1851, p. 145, *et seq.*

been again formed outside the last, viz., the present living reef (c c), and upon it the process of island-formation has commenced. This will also be eventually converted into a line of keys, into a continuous line of land, and be added in its turn to the peninsula. It is not probable that another reef will be formed outside of this, for the bottom slopes rapidly under the Gulf Stream, as seen in the section Fig. 126. In this process each reef dies when another is formed beyond it, for the water being protected by the outside reef becomes placid or lagoon water, and the strong reef-building species no longer flourish.

North of the line d d' the evidence is of the same kind, but less complete. True reef-rock, similar to that now forming on the reef, has been found at various points as far north as St. Augustine, on the eastern shore. The western shore and interior are less known. Tuomey in 1850 traced the Eocene on the west side as far as Tampa,[1] and Smith in 1880 even to the north shores of the Everglades.[2] The dotted line d' d'', therefore, gives the probable outline of the peninsula at the end of the Tertiary. If, however, as asserted by Agassiz, superficial patches of coral, of species identical with those still on the reefs, are found over this region, there must have been at least a temporary submergence during the Quaternary.

Mangrove Islands.—Mangrove-trees coöperate in an interesting manner with corals in the process of land-formation. These trees form dense jungles on the low, muddy shores of tropical regions. They are very abundant on the shores of Florida. They have the remarkable power of throwing out aërial roots from their trunks and branches, thus forming subordinate connections, with the ground or with the bottom of shallow water. From these may spring other trunks, which throw out similar roots, etc. Thus an inextricable entanglement of roots and branches continues to extend far beyond the actual shore-line. These form a nidus for the detention of sediments, and protect them from the action of waves ; and the shore-line thus steadily advances.

The seeds of the mangrove have also the faculty of shooting out long roots and stems, even while still attached to the parent tree. These shoots, falling into the water, float away, and if their roots touch bottom immediately fix themselves, grow into mangrove-trees, and commence multiplying in the manner described. Thus in the shoal water (e') are found mangrove islands in which there is no land, but only a mangrove forest, standing above water by means of their interlaced roots. By these, however, sediments are detained, and a true island is speedily formed. It is in this way that the small mangrove islands in the shoal water on the south and west of Florida are formed. They are entirely different from the wave-formed coral islands or keys. The hum-

[1] *American Journal of Science*, vol. i., p. 390, 1850.

[2] Ibid., vol. xxi., p. 292, 1881.

mocks in the Everglades have probably a similar origin, although some of them may possibly be of coral origin.

Florida Reefs compared with other Reefs.—In comparing the reefs just described with other reefs, it will be seen that the former are entirely unique. *No other reefs continuously make land.* In fringing reefs there is a small accretion about the shore-line of the previously-existing land, but this process is quickly limited. In barriers and atolls there is always *loss* of land, only a small fraction of which is recovered by coral and wave agency. But under these agencies Florida has steadily advanced southward more than 200 miles, and the area thus added to the continent is at least 20,000 square miles. It seems to us utterly impossible to account for this, except by supposing some other agency at work preparing the ground for the growth of successive reefs.

Probable Agency of the Gulf Stream.—Since corals cannot grow in water more than sixty to one hundred feet deep, it is evident that, unless subsidence goes on *pari passu* with the growth of the corals, a coral formation cannot be more than one hundred feet thick. But there is no evidence of subsidence on the coast or keys of Florida.[1] On the contrary, the *height of these parts is precisely the usual height of wave-formed islands, although no longer exposed to their action.* It follows, therefore, that the corals must have built upon an extensive submarine bank, produced by some other agency. Furthermore, since the reefs were formed successively one beyond another, it is evident that there must have been a progressive formation of this bank from the north toward the south. Such a progressive extension of a bank can only be formed by sedimentary deposit. It is impossible to conceive how such sedimentary deposit could have been formed, except by the Gulf Stream. It is to this agency, therefore, that we attribute the formation and extension of the bank upon which the corals grew.

We have already (p. 40) given reasons for believing that the Gulf Stream carries sediment in its deeper parts. Now, a current bearing sediment and sweeping around a deep curve, like the Gulf Stream around Florida (Fig. 125), must, as we have already shown (p. 22), continually deposit sediment on the interior of the curve, forming in the case of a river a bank above water, but, in the case of an oceanic stream, a submarine bank. This bank, in the case of the Gulf Stream, has been extending southward for ages almost inconceivable. On every part, as soon as it reached within 100 feet of the surface, corals built. Previous positions of the southern limit of the bank and of the successive reefs are shown in Fig. 126 in dotted outline.

[1] Evidences of subsidence, in the form of drowned corals, have been recently found by the Coast Survey in the course of the Gulf Stream off the Florida reefs, but this subsidence cannot have extended to the keys and peninsula, for this is inconsistent with the continual extension of land.

It is probable, therefore, that the southern portion of the peninsula of Florida is due to the coöperation of four or five different agencies, viz.: 1. The Gulf Stream building up a submarine bank to the dotted line n n, Fig. 126, within 100 feet of the surface; 2. Then corals building up to the surface; 3. Then waves raising it twelve to fifteen feet above the surface; 4. And, finally, *débris* from the peninsula on the one side, and the reef and keys on the other, filling up the intervening channels, and afterward raising the level of the swamps or Everglades thus formed; 5. In this last process the mangrove-trees have assisted.

The reefs of Florida are barrier reefs. Barriers are usually supposed to indicate subsidence. This is certainly true of the Pacific barriers, which commenced as fringes and became barriers by subsidence. But in Florida there has been no subsidence. They did not commence as fringes. The probable explanation is this: Corals will not grow in muddy water. On a gently-sloping shore with mud bottom, such as probably always existed on the southern shore of Florida, a fringing reef could not form, because the bottom would be always chafed by the waves and the water rendered turbid. But at a distance from shore, where such a depth was attained that the waves no longer chafed the bottom, a barrier would form, limited on the one side by the muddiness, and on the other by the depth, of the water.

Shell-Deposits.

Rivers carry carbonate of lime in solution to the sea (p. 76). In some bays, where large quantities of this material are carried by rivers running through limestone countries, the excess may be deposited as a *chemical* deposit. But in most cases sea-water contains less lime-carbonate than river-water. The reason is, that the lime-carbonate in sea-water is continually being drafted upon by organisms and deposited on their death as organic limestones. We have already shown how coral limestone is thus formed. But there are many other limestone-forming animals, and some species form other kinds of deposits besides limestone.

Molluscous Shells.—*Shallow-water deposits* of this kind are made principally by mollusca which, living in immense numbers near shore and on submarine banks, leave their dead shells generation after generation, and thus form sometimes pure shelly deposits, and sometimes shells mingled with sediments due to other agencies. On quiet shores the shells are quite perfect, whether imbedded in mud or forming shell-banks like our oyster-banks; but when exposed to the action of breakers, they are broken into coarse fragments, or even comminuted, worn into rounded granules, and cemented into shell-rock or oölitic rock. Such shell-rock and oölitic rock are now being formed on the coast of the Florida keys and of the West Indies. Similar rock is found in every

part of the world in the interior of continents. They indicate the existence in these places of a shore-line or of shallow water in some previous geological epoch.

Microscopic Shells.—Microscopic plants and animals are known to multiply in numbers with almost incredible rapidity. Many of them form no shell, and therefore are of no geological importance; but many species form shells of silica or of carbonate of lime, and these of course accumulate generation after generation, until important deposits are formed.

Fresh-water Deposits.—In streams, ponds, lakes, and hot springs, the beautiful siliceous shells of diatoms (uni-celled plants) accumulate without limit. The ooze at the bottom of clear ponds or lakes, as, for example, in the deepest parts of Lake Tahoe, consists often wholly of

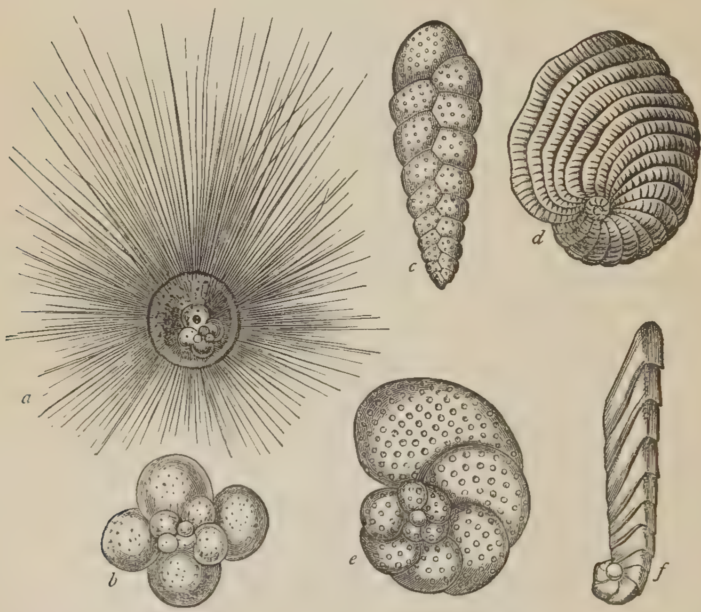


FIG. 127.—Shells of living *Foraminifera*. *a*, *Orbulina universa*, in its perfect condition, showing the tubular spines which radiate from the surface of the shell; *b*. *Globigerina bulloides*, in its ordinary condition, the thin hollow spines which are attached to the shell when perfect having been broken off; *c*, *Textularia variabilis*; *d*, *Peneroplis planatus*; *e*, *Rotalia concamerata*; *f*, *Cristellaria subarcuatula*. Fig. *a* is after Wyville Thomson; the others are after Williamson. All the figures are greatly enlarged (after Nicholson).

these shells. Diatoms live also in great numbers in the hot springs of California and Nevada, and the deposits of such springs sometimes consist wholly of these shells. Thick strata, belonging to earlier geological times, are found wholly composed of diatoms. We are thus able to explain the formation of these strata.

Deep-sea Deposits.—Over nearly all the bottom of deep seas, beyond the reach of sedimentary deposits, we find a white, sticky ooze, composed of the carbonate-of-lime shells of microscopic animals (foraminifers) Fig. 127, and microscopic plants (coccospheres). Some of these seem to be *living*, or recently dead; some dead and empty, but still perfect; but most of them completely disintegrated. On account of the great abundance of the shells of one form of foraminifera, this soft, white mud is called *globigerina ooze.* Mingled in considerable numbers among the calcareous shells are others of silica. These are also partly animals (radiolaria) and partly plants (diatoms). The extraordinary resemblance of this deep-sea ooze, both in chemical and microscopic character, to chalk, leaves no room for doubt that chalk was formed in this way.

SECTION 4.—GEOGRAPHICAL DISTRIBUTION OF ORGANISMS.

Fauna and Flora.—The animals and plants inhabiting any country are called the fauna and flora of that country. In a more scientific sense, however, a natural fauna or flora is a group of organisms inhabiting one locality, differing conspicuously from other natural groups inhabiting other localities. All the members of such a natural group must bear certain harmonic relations to one another, and the whole group to the external physical conditions. Moreover, each group is circumscribed and separated from other neighboring groups by limiting physical conditions.

Kinds of Distribution.—Distribution of organisms is of two general kinds, viz., distribution in *space* and distribution in *time*, or *geographical* distribution and *geological* distribution. There are, therefore, geographical faunas and floras and geological faunas and floras. A geographical fauna is the group of animals inhabiting any natural geographical region. Thus the animals of Australia form a distinct fauna, differing entirely from any other upon the earth's surface. A geological fauna is the whole group of animals inhabiting the earth at one epoch, and differing from that of other epochs. Thus the whole group of animals inhabiting the earth during what geologists call the secondary period form a distinct fauna, differing remarkably from all preceding or subsequent faunas. The flora of the coal period is very distinct from all others.

The organisms of every epoch, however, were distributed over the earth's surface in separate faunas and floras. Every geological fauna and flora is, therefore, divisible into more or less distinct geographical faunas and floras. Geological faunas and floras will form the principal subject of Part III. We propose now to study only geographical distribution of organisms at the present time, this portion of geology being concerned only with "causes now in operation." We study the

laws of geographical distribution in the present epoch because it throws light on the geographical distribution in previous epochs, and also on the laws of geological distribution, or the history of organisms. It also, as will be shown hereafter, furnishes a key to former changes in physical geography and former migrations of species.

Among physical conditions limiting the distribution of organisms, one of the most important is *temperature.* We will, therefore, first speak of temperature-regions, confining ourselves, for the sake of greater clearness, to plants. The principles thus established we will then extend and modify. And, further, since temperature-regions may be either *vertical* or *horizontal* in latitude, we will commence with

Vertical Botanical Temperature-Regions.—To explain vertical distribution we will take the case of a mountain, at or near the equator, because all the vertical regions are there represented. If we pass from base to summit of such a mountain we will traverse, first, a *region of palms*, so called because the vegetation is characterized by the abundance of palms and palm-like plants, such as bananas, tree-ferns, etc. The second region traversed is characterized by the prevalence of evergreens, such as myrtles, laurels, etc., and ordinary deciduous trees, such as hickory, oaks, elms, poplars, etc.; and therefore may be called the region of ordinary forest or *hard-wood* trees. The third region traversed is characterized by the prevalence of pines and other conifers, and therefore called the *region of pines.* The fourth region contains few or no trees, but only shrubs and Alpine herbaceous plants, and therefore may be called the Alpine or *treeless region.* The fifth, being the region of *perpetual snow*, *is plantless*, or nearly so.

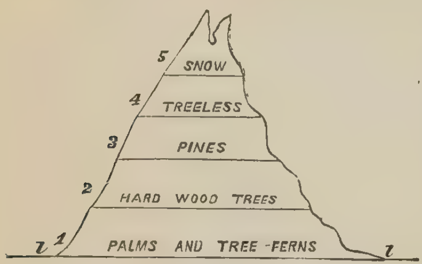


FIG. 128.

Botanical Temperature-Regions in Latitude.—As the regions above spoken of are determined entirely by temperature, it is evident that they must be reproduced in latitude in zones where these limiting temperatures successively reach the earth's surface. Thus, if *a* (Fig. 129) represents an equatorial mountain, the temperatures which limit the botanical regions will approach the earth as we go toward either pole, as shown by the dotted lines, and successively reach the sea-level, giving rise to similar zones of temperature, and therefore to similar botanical regions, extending all around the earth.

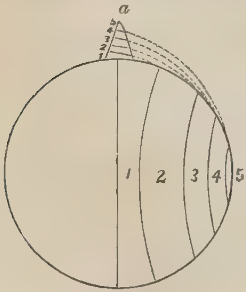


FIG. 129.

These zones, being temperature-zones, are not limited by parallels of latitude as represented in the figure, but by isothermal lines. In passing from the equator to the poles, we traverse: 1. A region of palms, or tropical zone; 2. A region of ordinary forest or hard-wood trees, evergreen and deciduous, or subtropical and temperate zone; 3. A region of pines and birch, or cold temperate and subarctic zone; 4. A treeless region, or arctic zone. The fifth or plantless region can hardly be said to exist at the sea-level in any part of the earth.

Further Definition of Regions.—1. The regions we have given are characterized by the prevalence of certain *orders* of plants; but the same law of limitation applies with still greater force to *families*, *genera*, and *species*. These smaller classification-groups are still more limited in range. Thus palms range over the whole of region No. 1 (Fig. 129); but one genus of palms may occupy the warmer or equatorial part, and another genus the higher or tropical parts. Thus, generally, the range of families is more restricted than that of orders, the range of genera than that of families, and the range of species than that of genera. Thus, these regions may be divided into subordinate regions, and these again into still more subordinate regions. What we further say will have reference principally, though not entirely, to species. 2. We have separated these regions by lines. It must not be supposed, however, that these limits are distinctly marked. On the contrary, they shade insensibly into each other. Some species of palms, etc., pass into the region of hard-wood trees, and *vice versa*. Many species of hard-wood trees pass into the region of pines, and *vice versa*. So, also, the sub-regions of families, genera, and species, cannot be separated by hard lines. They shade insensibly into, interpenetrate, or overlap one another at their margins. Thus if $a\,a'$ and $b\,b'$ (Fig. 130) be the range, either vertical or horizontal, of two species, then in the zone $b\,a'$ the two species coexist. 3. In any region or sub-region the organic forms which characterize it are most abundant in the middle portion, and become less and less abundant toward the margin, where they disappear. If the line $a\,a'$ (Fig. 130) represents the range of any species, then the breadth of the elliptical area will represent the relative abundance of individuals in different parts of the range. 4. Although, therefore, species, so far as numbers of individuals are concerned, come in gradually on the margin of their natural region, reach their greatest abundance in the middle portion, and again gradually die out on the other margin, yet in *specific characters* we see usually no such gradual transition. In specific character they seem to come in suddenly, to remain substantially unchanged throughout their range, and pass out suddenly on the other margin. Thus, to take a single instance: in passing from

Fig. 130.

the equator to the poles, at a certain latitude, the sweet-gum or liquid-amber tree first appears, few in number; it increases in number in the middle part of its range, and finally again diminishes in number and gradually disappears. But throughout its whole range this species is unmistakably the same—it does not pass into any other species. It is *as if* the species had originated somehow (we will not now discuss how) in the area where we find it, and had extended its range as far as physical conditions and the struggle for life with other species would permit. 5. We have seen that the botanical zones in elevation and in latitude are similar to one another in the great orders which characterize them; but they are by no means identical in genera and species. This follows from what we have said under 4. The vertical and horizontal zones No. 1 being in direct connection with one another, the species are to a large extent identical. But between zones No. 2 communication is impossible, except through zone No. 1, but this is forbidden by physical conditions; and, therefore, although forest-trees may exist in both, the species are all different. The same is true of zones Nos. 3 and 4, and also of corresponding zones north and south of the equator. It is *as if* the present species had originated in the areas where we now find them, and had not been able to mingle on account of temperature barriers intervening. 6. Although, when no physical obstacle intervenes, regions or zones in latitude like those in elevation shade insensibly into one another by interpenetration, as already explained, yet when physical barriers, such as an east-and-west mountain-chain, occur, no such shading is possible; but, on the contrary, there is an abrupt change. Thus, north and south of the Himalaya Mountains, or north and south of the Sahara Desert, the plants are entirely different, apparently because interpenetration of contiguous floras by spreading is impossible in this case.

Zoological Temperature-Regions.—We have spoken first of *plants*, because, being fixed to the soil, they illustrate more clearly the natural laws of distribution as determined by temperature. Animals, by their power of locomotion and migration with the seasons, interfere seriously with the simplicity of these laws. Although families, genera, and species of animals, like plants, are limited in their range, particular forms characterizing certain zones—as monkeys, parrots, elephants the torrid zone, and walruses and white bears the polar zone—yet it is impossible to divide the surface of the earth into zones characterized by particular orders in the same broad, general way as in the case of plants. Nevertheless, all that we have said concerning the limitation of range of families, genera, and species, and the manner in which contiguous regions or sub-regions shade into one another, applies with equal force to animals. The apparent *fixity* of animal species within certain narrow limits of variation is even more striking than in the case of plants.

What we shall further say will apply to animals and plants without distinction.

Continental Fauna and Flora.—If no physical barriers intervened, there seems to be no reason why the fauna and flora of each zone of temperature should not be continuous all around the earth. But impassable barriers exist in the form of oceans separating continents, and on the continents in the form of north-and-south ranges of mountains. Consequently, on the supposition of the local origin of species, it follows that, although the orders and sometimes families of animals and plants are similar on the two continents, the species and many of the genera are entirely different. That this diversity is the result of impassable barriers is sufficiently proved by the fact that most species of

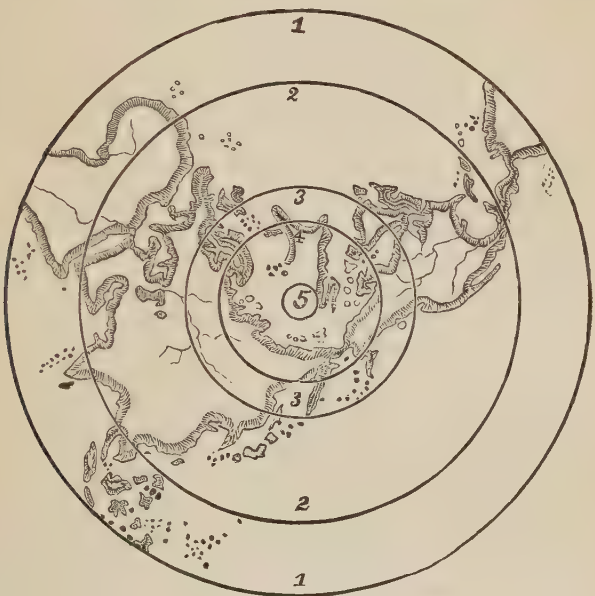


FIG. 181.

animals or plants, introduced from one continent to the corresponding zone of another, flourish well, and soon become permanent members of the fauna or flora of their adopted country. We will now discuss the subject in more detail.

The accompanying figure (Fig. 131) is a view of the northern hemisphere, the circumference being the equator and the centre the north-pole, and the circular zones being the same as already described. These, however, will not be regular circles as represented in the figure, but will be isothermal zones. They really run farther north in Europe,

and farther south in North America, than represented in the figure. Now, comparing the eastern and western continents with one another, commencing with the arctic zone No. 4, we find that in this zone the fauna and flora are nearly identical in the two continents, the reason being, apparently, their close approximation to one another in this zone, and their connection by means of solid ice. In the next zone, No. 3, the species are already quite different; and in No. 2, to which the United States and Europe mostly belong, nearly all the species, and many of the genera, and even some families, are different. The few exceptions to the universal diversity of the fauna and flora of this country, as compared with Europe and Asia, are principally: 1. Introduced species; 2. Species of wide range, either by reason of great hardihood or by extensive migration, and which, therefore, belong to No. 4 as well as Nos. 3 and 2; and, 3. Alpine species, which seem to have extended, during a former cold epoch (Glacial epoch), from No. 4 to No. 3 in both continents, and with the return of milder climate have retreated, some northward, and some up the sides of the mountains of No. 3, to their appropriate zone of temperature. In No. 1 the difference between the two continents is still greater, and continues without abatement into corresponding zones of the southern hemisphere, since these do not approach each other toward the pole as they do at the north. Thus, we find the fauna and flora of South America and Africa as different as possible. As an illustration of this, we will only mention the prehensile-tailed monkeys, sloths and armadillos, llamas and toucans, humming-birds, among animals, and the cacti among plants, as characteristic of South America; and the lions, tigers, elephants, rhinoceroses, hippopotamuses, giraffes, and the tailless monkeys, of Africa.

Subdivisions.—The continental faunas and floras are again subdivided in longitude by north-and-south mountain-chains. Thus the fauna and flora of the United States are divided by the Rocky Mountain and Appalachian chains into three sub-faunas and sub-floras, viz., an Atlantic slope, an interior continental, and a Pacific slope fauna and flora. The difference between the Atlantic slope and the interior continental region is not great, because the mountain-barrier is not so high but it may be overpassed. The Rocky Mountains being a wider and higher and therefore the more impassable barrier, the fauna and flora of the Pacific slope are very distinct, almost all its species being peculiar to that region. The exceptions are mostly strong-winged birds. In a similar manner in South America the Andes chain separates faunas and floras which are very distinct, and in the eastern continent the Ural Mountains separate a European from an Asiatic fauna and flora. Subdivisions of this kind are more marked in the case of plants and of those animals which are closely connected with plants, such as insects, than in

the case of higher animals which have a greater power of locomotion, and therefore of overcoming obstacles.

Special Cases.—We might mention many special cases of remarkable groups of animals and plants, especially on isolated islands. We will only mention a few by way of illustration: 1. The fauna and flora of Australia are perhaps the most remarkable in the world. Not only are the species different, but the genera, families, and orders, are peculiar to this continent. So remarkably and conspicuously is this the fact, that even the unscientific traveler is at once struck with the strange appearance of the vegetation and the animals—trees with narrow, rigid leaves twisted on their leaf-stalk so as to turn their edges to the sky; the mammals, about 200 species, nearly all belonging to the non-placentals, including marsupials and monotremes, a great sub-class of quadrupeds to which the kangaroos, the opossums, and the ornithorhynchus belong, and which are confined to Australia, with the exception of several species of opossum found in America. The island of *Madagascar* is another remarkable zoölogical province. All the animals on this island, with one single exception, are peculiar, being found nowhere else. This exception is that of a small quadruped supposed to have been introduced. On the *Galapagos*, a small group of islands at a considerable distance from the west coast of South America and from all other islands, all the animals are entirely different from those of any part of the world. Reptiles of peculiar species abound, but no mammal, except one species of mouse, has yet been found.

Thus we see that species are limited in one direction by temperature, and in all directions by physical barriers. If we now add to these limitations also peculiar climates and soils (such, for example, as the dry plains of Utah and Arizona), which limit vegetation, and therefore animals, we easily perceive that all these limiting causes produce groups of species confined within certain areas differing from other groups, sometimes overlapping them, sometimes trenchantly separated.

We have said that the differences between faunas or floras are in proportion to the impassableness of the barriers; but there is another important element—viz., the *time* during which the barrier has existed. This element of time connects geographical faunas with geological changes, and thus geographical distribution of species becomes the key to the most recent of these changes. This important subject will be again touched in our discussion of the Glacial epoch.

Taking all causes into consideration, the whole earth has been divided into six principal faunal regions, viz.: 1. *Nearctic*, including North America, exclusive of Central America; 2. *Neotropic*, including Central and South America; 3. *Palæarctic*, including Europe, North Africa, and Asia north of the Himalayas; 4. *African*, including Africa

south of the Sahara ; 5. *Indian or Oriental*, including Asia south of the Himalayas, and the adjacent islands ; 6. *Australian*, including Australia, New Zealand, New Guinea, and South-Sea Islands, etc. These primary regions are subdivided into provinces and sub-provinces according to the principles already explained. For example, the nearctic has been subdivided into four provinces, viz., (*a*) the Alleghanian, (*b*) the Rocky Mountain, (*c*) the Californian, and (*d*) the Canadian.

Marine Fauna.—Distribution in Latitude.—In passing along the shores of Europe or of America, from south to north, we find that the species of marine animals, such as molluscous shells and fishes, gradually change, one species being replaced by another in the manner already explained. If the change of temperature be gradual, the change of fauna will also be gradual; but if the change, from any cause, be sudden, the change of species will be correspondingly sudden. Thus, for example, on the coast of the United States, Cape Hatteras and Cape Cod divide the littoral fauna into three quite distinct subdivisions, changing somewhat suddenly at these points, viz., a Southern, a Middle States, and a New England, fauna. The reason is that the Gulf Stream hugs the shore as far as Hatteras, thus carrying the southern fauna northward beyond its natural limit, and then turns away from the coast. On the other hand, the arctic current hugs the New England coast as far as Cape Cod, bringing with it an arctic fauna, and then leaves the surface and goes downward.

Distribution in Longitude.—Both land and deep sea are impassable barriers to marine species. Hence we find that the marine species on the east and west coasts of each continent, as well as those inhabiting the east and west shores of the same ocean, are almost entirely different. Thus the marine species on our Atlantic shores are not only different from those of our Pacific shores, but also from those on the Atlantic shores of Europe and Africa. The same is true of the species on the two shores of the Pacific, as compared with one another, or with those of Europe. The exceptions to the general rule, that the marine species of different shores are different, are principally arctic species of wide range, such as whales, etc.

Depth and Bottom.—It is found that marine species vary with the depth, so that there are littoral species, and deep-water species, and profound sea-bottom species. Also the species on sand-bottoms are different from those on mud-bottoms.

Special Cases.—The marine fauna of Australia, like its land fauna, is very peculiar, differing from all others, not only in species, but in genera and families. It is also a remarkable fact that some of its fishes belong to families once abundant in the seas everywhere, but now extinct except in these waters. The marine shells of almost every isolated island in the ocean are peculiar. This is still more true of land and

fresh-water shells of islands and even of different rivers of the same continent. A remarkable illustration of this is found in the species of the common river-mussels. Almost every large river in the United States has some species of shell peculiar to it. Nearly all the shells of the Altamaha River are peculiar, being found nowhere else on the face of the earth.

Thus in all cases species in different localities are different in proportion to the height or depth and the width of the intervening barriers, and (most important of all) also in proportion to the *length of time* since these barriers were established. These facts are now so well attested that they are used as a basis of reasoning. If two countries now separated have species identical, we are sure that they have been only very recently separated. The substantial identity of the species of England and those of contiguous Europe shows that the British Isles have been connected with the Continent at a period geologically very recent. The general resemblance, though not identity, of some plants on the Pacific coast and in Japan, produces a strong conviction that the two continents have been formerly connected in the region of the Aleutian Isles. The great distinctness of the fauna of Australia indicates a long period of isolation from all other continents. It is as if there had been a slow change of species in *time*, and after separation each group had taken its own way, and thus become more and more different. This subject, however, cannot be further discussed at present.

PART II.

STRUCTURAL GEOLOGY.

CHAPTER I.

GENERAL FORM AND STRUCTURE OF THE EARTH.

1.—*Form of the Earth.*

The form of the earth is that of an oblate spheroid flattened at the poles. The polar diameter is less than the equatorial diameter by about twenty-six miles, or about $\frac{1}{300}$ of the mean diameter.[1] The highest mountains, being only five miles high, do not interfere greatly with the general form.

This form, being precisely that which a fluid body revolving freely would assume, has been regarded by many of the most distinguished physicists as conclusive evidence of the former fluid condition of the earth. The argument may be stated as follows: 1. A fluid body standing still, under the influence only of its own molecular or gravitating forces, would assume a perfectly spherical form; but, if rotating, the form which it would assume, as the only form of equilibrium, is that of an oblate spheroid, with its shortest diameter coincident with the axis of rotation. Now, this is precisely the form not only of the earth, but, as far as known, of all the planetary bodies. 2. In an oblate spheroid of rotation the oblateness increases with the rapidity of rotation. Now, Jupiter, which turns on its axis in ten hours, is much more oblate than the earth. The flattening of the earth is only about $\frac{1}{300}$ of its diameter, while that of Jupiter is about $\frac{1}{15}$. 3. The forms of the earth and of Jupiter have been calculated; the data of calculation being the former fluidity, the time of rotation, and an assumed rate of increasing density from surface to centre; and the calculated form comes out nearly the same as the measured form.

The force of this argument, however, has been, to say the least, greatly exaggerated. The oblateness of the earth and planets, as has been shown by Playfair and Herschel,[2] only proves that they have assumed their form under the influence of rotation—that they are spheroids of rotation—but not that they have ever been in a fluid condition. For since a rotating body, whatever be its form, always *tends* to assume an oblate spheroid form, and since the materials on the sur-

[1] More exactly $\frac{1}{293.5}$, *Philosophical Magazine*, vol. x., p. 121, 1880.

[2] Lyell, "Principles of Geology," vol. ii., p. 199.

face of the earth are in continual motion, being shifted hither and thither under the influence of atmospheric and aqueous agencies, it is evident that the final and total result of such motions must be in the course of infinite ages to bring the earth to the only form of equilibrium of a rotating body, viz., an oblate spheroid. If, for example, the earth were spherical, standing still and covered with water, and then set rotating, the waters would gather into an equatorial ocean, and the land be left as polar continents. But this condition would not remain ; for atmospheric and aqueous agencies, if unopposed, would eventually cut down the polar continents and deposit them as sediments in the equatorial seas, and the solid earth would thus become an oblate spheroid. This final effect of degrading agencies would not be opposed by igneous agencies, as the action of these is irregular, and does not tend to any particular form of the earth. Yet this applies only to the *general* spheroidal form ; for Hennessey has shown[1] that, although the spheroidal form would be assumed either by fluidity or by abrasion, yet the *degree* of ellipticity of the spheroid would be different, and probably sensibly different, in two cases, being greater in the former ; and that the actual form of the earth more nearly approaches this greater degree.

Therefore, although there are many reasons, drawn both from geology and from the nebular hypothesis, for believing that the earth was once in an incandescent fluid condition, and that it then assumed an oblate spheroid form in obedience to the laws of equilibrium of fluids ; yet this form alone must not be assumed as demonstrative proof of such original condition, since a similar form would be produced by causes now in operation on the earth-surface, whatever may have been its original form and condition. Moreover, it is evident that the exact original form, however determined, cannot have been retained, for there are causes in operation which have tended constantly to modify it. If abrasion can produce, it can also modify the form of the earth. If the form of the earth is a form of equilibrium, then a change in the *rate* of rotation will produce a change in the *degree* of oblateness or ellipticity. Now, when the earth first solidified from an incandescent liquid condition, it had a certain degree of ellipticity determined by its rate of rotation ; but this rate of rotation has not been constant. The earth, from that time until now, has been cooling and contracting; and contraction would tend to accelerate rotation and *increase* ellipticity. But, also, ever since an ocean was first formed by precipitation on the cooling earth, tides have been formed by the moon and sun, and the *friction of the dragging tides* would tend to retard rotation and *decrease* ellipticity. At first, doubtless, the contractional acceleration prevailed and ellipticity increased ; but now tidal retardation prevails, and ellipticity is probably decreasing.

[1] *Philosophical Magazine*, vol. vii., p. 67, 1879, vol. x., p. 119, 1880, and vol. xi., p. 283, 1881.

2.—*Density of the Earth.*

The mean density of the earth, as determined by several independent methods, is about 5.6. The density of the materials of the earth-surface, leaving out water, is only about 2 to 2.5. It is evident, therefore, that the density of the central portions must be much more than 5.6. This great interior density may be the result—1. Of a *difference of material.* It is not improbable that the surface of the earth has become oxidized by contact with the atmosphere, and that at great depths the earth may consist largely of metallic masses. Or the great interior density may be the result—2. Of condensation by the immense pressure of the superincumbent mass. In either case the tendency of *increasing heat* would be to diminish the increasing density. But how much of the greater density is due to difference of material and how much to increasing pressure, and how much these are counterbalanced by expansion due to increasing heat, it is impossible to determine.

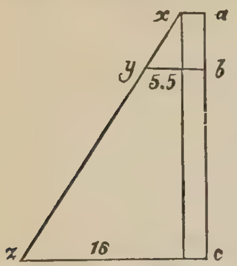


FIG. 132.—Diagram illustrating the Increasing Density of the Earth.

The increase of density has been somewhat arbitrarily assumed to follow an arithmetical law. Under this condition a density equal to the mean density would be found at $\frac{1}{4}$ radius from the surface, and taking the surface density at 2, and the mean density at 5.5, the *central* density would be 16. In the diagram (Fig. 132), if $a\ c =$ radius, the ordinate $a\ x =$ surface density $= 2$, and $b\ y$ $=$ mean density $= 5.5$, then $c\ z$, the central density, will be $= 16$.

It is needless to say that this result (Plana's) is unreliable.

3.—*The Crust of the Earth.*

The surface of the earth undoubtedly differs greatly in many respects from its interior, and therefore the exterior portion may very properly be termed a *crust.* It is a *cool* crust, covering an *incandescent* interior ; a *stratified* crust, covering an *unstratified* interior ; probably an *oxidized* crust, covering an *unoxidized* interior ; and many suppose a *solid* crust, covering a *liquid* interior. This last idea, which, however, we have shown (p. 79) to be very doubtful, has probably given rise to the term *crust.* The term, however, is used by all geologists, without reference to any theory of interior condition, and only to express that portion of the exterior which is subject to human observation. The thickness which is exposed to inspection is about ten to twenty miles.

Means of Geological Observation.—The means by which we are enabled to inspect the earth below its immediate surface are : 1. *Artificial sections,* such as mines, artesian wells, etc. These, however, do

not penetrate below the insignificant depth of half a mile. 2. *Natural sections*, such as cliffs, ravines, cañons, etc. These, as we have already seen (p. 17), sometimes penetrate 5,000 to 6,000 feet. 3. Tilting, and subsequent erosion, of the rocks, by which strata from great depths have their edges exposed. Thus, in passing along the surface from *a* to *b* (Fig. 133), lower and lower rocks are successively brought under inspection. This is by far the most important means of observation; without it the study of geology would be almost impossible. 4. Volcanoes bring up to the surface materials from unknown but probably very great depths.

Ten miles seem an insignificant fraction of the earth's radius, being, in fact, equivalent to less than one-thirtieth of an inch in a globe two

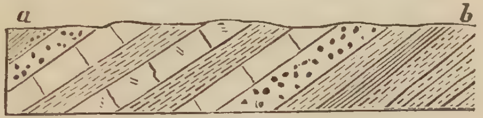


FIG. 133.

feet in diameter. It may seem at first sight an insufficient basis for a science of the earth. We must recollect, however, that only this crust has been inhabited by animals and plants—on this crust only have operated atmospheric, aqueous, and organic agencies—and therefore on this insignificant crust have been recorded all the most important events in the history of the earth.

4.—*General Surface Configuration of the Earth.*

The earth-surface is very irregular. The hollows are occupied by the ocean, and the protuberances constitute the continents and islands. Nearly three-quarters of the whole surface is covered by the ocean. The mean height of the continents, according to the most recent results, is as follows: Europe, 984 feet; Asia and Africa, 1,640 feet; America, North and South, 1,083 feet; Australia, 820 feet. The mean height of all land is given as about 1,378 feet.[1] These figures are considerably greater than those given by Humboldt and heretofore adopted.

The mean depth of the ocean is probably 12,000 to 15,000 feet (Thompson). There is probably water enough in the ocean, if the inequalities of the earth-surface were removed, to cover the earth to a depth of at least 8,000 to 9,000 feet.

The extreme height of the land above the sea-level is five miles, and the extreme depth of the ocean is at least as much. The extreme relief of the solid earth is therefore not less than ten miles.

Cause of Land-Surfaces and Sea-Bottoms.—The most usual idea among geologists as to the general constitution of the earth is that the earth is still essentially a liquid mass, covered by a solid shell of twen-

[1] Krümmel, *American Naturalist*, vol. xiii., p. 464, 1879.

ty-five to thirty miles in thickness; and that the great inequalities, constituting land-surfaces and ocean-bottoms, are produced by the up-bending and down-bending of this crust into convex and concave

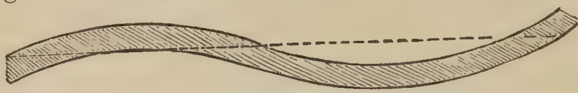


FIG. 134.

arches, as shown in Fig. 134. The clear statement of this view is sufficient to refute it; for, when it is remembered that the arches with which we are here dealing have a span of nearly a semi-circumference of the earth, it becomes evident that no such arch, either above or below the mean level, could sustain itself for a moment. The only condition under which such inequalities could sustain themselves on a supporting liquid is the existence of inequalities on the under surface of the crust next the liquid, similar to those on the upper surface, but in reverse, as shown in Fig. 135. And these lower or under-surface

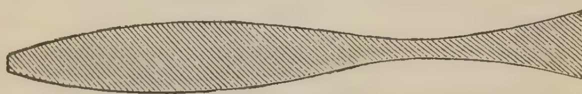


FIG. 135.—Diagram illustrating the Conditions of Equilibrium of a Solid Crust on a Liquid Interior.

inequalities would have to be repeated not only for the largest inequalities, viz., continental surfaces and ocean-bottoms, but also for great mountain plateaus. And thus the hypothesis breaks down with its own weight.[1]

Besides, we have already given good reasons (pages 79 and 80) for believing that the earth is substantially solid. Upon the hypothesis of a substantially solid earth, we explain the great inequalities constituting continental surfaces and ocean-bottoms by *unequal radial contraction* of the earth in its secular cooling.

It is evident that, in such secular cooling and contraction, unless the earth were perfectly homogeneous, some parts, being more conductive, would cool and contract more rapidly in a radial direction than others. Thus some radii would become shorter than others. The more conductive, rapidly-contracting portions, with the shorter radii, would become sea-bottoms; and the less conductive, less rapidly-contracting portions, with the longer radii, land-surfaces. In other words, the solid earth in contracting becomes slightly deformed, and the water collects in the depressions.[2]

It is only the greatest inequalities, viz., land-surfaces and sea-bottoms, which we account for in this way. Mountain-chains are certainly

[1] It has been shown by G. H. Darwin that the great inequalities of the earth's surface could not be sustained unless the earth be as rigid as granite for a depth of 1,000 miles.—"Proceedings of the Royal Society," June, 1881.

[2] See APPENDIX.

formed by a different process, which we will discuss under that head (p. 250); and it is even possible that the causes which operate to produce mountain-chains may also produce these greater inequalities.

The continuance of these causes would tend constantly to increase the extent and height of the land, and to increase the depth, but diminish the extent of the sea. This, on the whole, seems to have been the fact during the history of the earth, as will be shown in Part III. Nevertheless, local causes, both aqueous and igneous, as already shown in Part I., have greatly modified the general contour, both map and profile, given by secular contraction.

Laws of Continental Form.—That the general contour of continents and sea-bottoms has been determined by some general cause, such as secular contraction, affecting the whole earth, is further shown by the laws of continental form. The most important of these are as follows:

1. Continents consist of a great interior basin, bordered by elevated coast-chain rims. This typical form is most conspicuously seen in North and South America, Africa, and Australia. Europe-Asia is more irregular, and therefore the typical form is less distinct. We

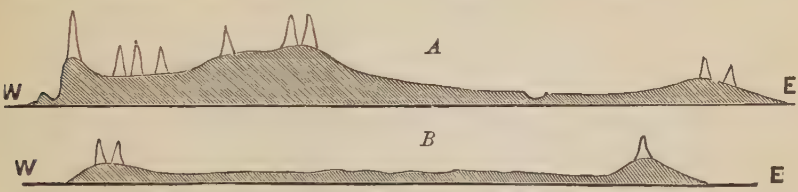


FIG. 136.—*A*, Section across North America (after Guyot); *B*, Section across Australia (after Guyot).

give in Fig. 136, *A* and *B*, an east-and-west section of North America and of Australia, as typical examples of continental structure.

The great rivers of the world, e. g., the Nile, Mississippi, Amazon, La Plata, etc., drain these interior continental basins.

2. In each continent the greatest range of mountains faces the greatest ocean. Thus in America the greatest range is on the west, facing the Pacific; while in Africa the greatest range is on the east, facing the Indian Ocean. In Asia the Himalayas face the Indian Ocean, while the Altai face the Polar Sea. In Australia the greatest range is to the east, facing the Pacific.

3. The greatest ranges have been subjected to the greatest and most complex foldings of the strata, and are the seats of the greatest metamorphism (p. 221) and the greatest volcanic activity.

4. The outlines of the present continents have been sketched in the earliest geological times, and have been gradually developed and perfected in the course of the history of the earth. In the case of the North American Continent this will be shown in Part III.

The cause of some of these laws will be discussed under the head of Mountain-Chains.

Rocks.

In geology the term *rock* is used to signify any material constituting a portion of the earth, whether hard or soft. Thus, a bed of sand or clay is no less a rock than the hardest granite. In fact, it is impossible to draw any scientific distinction between materials founded upon hardness alone. The same mass of limestone may be soft chalk in one part and hard marble in another; the same bed of clay may be hard slate in one part and good brick-earth in another; the same bed of sandstone may be hard gritstone in one part and soft enough to be spaded in another. The same volcanic material may be stony, glassy, scoriaceous, or loose sand or ashes.

Classes of Rocks.—All rocks are divided into two great classes, viz., *stratified rocks* and *unstratified rocks.* Stratified rocks are more or less consolidated sediments, and are usually, therefore, more or less *earthy* in structure and of *aqueous origin.* Unstratified rocks have been more or less completely fused, and therefore are *crystalline* in structure and of *igneous origin.*

CHAPTER II.

STRATIFIED OR SEDIMENTARY ROCKS.

Section 1.—Structure and Position.

Stratification.—Stratified rocks are characterized by the fact that they are separated by parallel division-planes into larger sheet-like masses called *strata*, and these into smaller *layers* or *beds*, and these again into still smaller *laminæ.* These terms are purely relative, and are therefore somewhat loosely used. Usually, however, the term *stratum* refers to the mineralogical character; the term *layer* to subdivisions of a stratum distinguishable by difference of color or fineness; and the term *lamina* to those smallest subdivisions, evidently produced by the sorting power of water. For instance, in the annexed figure, *a*, *b*, and *c*, are three strata of sandstone, clay, and limestone, each divisible into two layers differing in fineness or compactness of the material, and all finely laminated by the sorting power of water. The lamination, however, is not represented, except in the clay stratum, *b*.

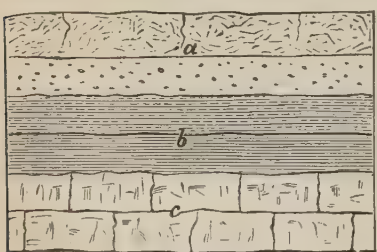


Fig. 187.—Stratification.

Extent and Thickness.—Probably nine-tenths of the surface of the land, and, of course, the whole of the sea-bottom, are covered with stratified rocks. This proves that every portion of the surface of the earth has been at some time covered with water. The extreme thickness of

stratified rocks is certainly not less than twenty miles; the average thickness is probably several miles.

Kinds of Stratified Rocks.—Stratified rocks are of three kinds, and their mixtures, viz., *arenaceous* or sand rocks, *argillaceous* or clay rocks, and *calcareous* or lime rocks. Arenaceous rocks, in their incoherent state, are *sand*, *gravel*, *shingle*, *rubble*, etc., and in their compacted state are *sandstones*, *gritstones*, *conglomerates*, and *breccias*. Conglomerates are composed of *rounded* pebbles, and breccias of *angular* fragments cemented together. Argillaceous rocks, in their incoherent state, are *muds* and *clays;* partially consolidated and finely laminated they form *shales*, and thoroughly consolidated they form *slates*. Calcareous rocks are *chalk*, *limestone*, and *marble*. They are seldom in an incoherent state, except as *chalk*.

These different kinds of rocks graduate into each other through intermediate shades. Thus we may have *argillaceous sandstones*, *calcareous sandstones*, and *calcareous shales* or marls.

The most important points connected with stratified rocks we will now, for the sake of greater clearness, bring out in the form of distinct propositions. On these propositions is based nearly the whole of geological reasoning.

I. Stratified Rocks are more or less Consolidated Sediments.—The evidence of this fundamental proposition is abundant and conclusive. 1. Beds of mud, clay, or sand, as already stated, may often be traced by insensible gradations into shales and sandstones. 2. In many places the process of consolidation is now going on before our eyes. This is most conspicuous in sediments deposited at the mouths of large rivers whose waters contain abundance of carbonate of lime in solution, or on the coasts of seas containing much carbonate of lime. Thus the sediments of the Rhine are now consolidating into hard stone (p. 76), and on the coasts of Florida, Cuba, and on coral coasts generally, comminuted shells and corals are quickly cemented into solid rock (p. 148). 3. All kinds of lamination produced by the sorting power of water which have been observed in sediments, have also been observed in stratified rocks. 4. Stratified rocks contain the remains of animals and plants, precisely as the stratified mud of our present rivers contains river-shells, our present beaches sea-shells, or the mud of our swamps the bones of our higher animals drifted from the high lands. 5. Impressions of various kinds, such as ripple-marks, rain-prints, footprints, etc., evidently formed when the rock was in the condition of soft mud, complete the proof. It may be considered as absolutely certain that *stratified rocks are sediments*. Arenaceous and argillaceous rocks are the *débris* of eroded land, and are therefore called *mechanical* sediments or *fragmental* rocks. Limestones are either chemical deposits in lakes and seas, or are the comminuted remains of organisms. They

are therefore either chemical or organic sediments. Conglomerates, grits, and sandstones, indicate violent action; shales and clays quiet action in sheltered spots. Limestones are sometimes produced by violent action—e. g., coral breccia—sometimes very quiet action, as in deep-sea deposits.

We have already seen (p. 4) that rocks under atmospheric agencies are disintegrated into soils, and these soils are carried by rivers and deposited as sediments in lakes and seas. Now we see that these sediments are again in the course of time consolidated into rocks, to be again raised by igneous agencies into land, and again disintegrated into soils, and redeposited as sediments. Thus the same material has been in some cases worked over many times in an ever-recurring cycle. This is another illustration of the great law of circulation, so universal in Nature.

Cause of Consolidation.—The consolidation of sediments into rocks in many cases is due to some *cementing principle*, such as carbonate of lime, silica, or oxide of iron, present in percolating waters. In such cases the consolidation often takes place rapidly. In other cases it is due to *long-continued heavy pressure*, and in still others to *long-continued*, though not necessarily very great, *elevation of temperature* in presence of water. In these cases the process is very slow, and therefore it has not progressed greatly in the more recent rocks.

II. Stratified Rocks have been gradually deposited.—The following facts show that in many cases rocks have been deposited with extreme slowness : 1. Shales are often found the lamination of which is beautifully distinct, and yet each lamina no thicker than cardboard. Now, each lamina was separately formed by alternating conditions, such as the rise and fall of tide, or the flood and fall of river. 2. Again, on the *interior* of imbedded shells of mollusca, or on the outer surface of the shells of sea-urchins *deprived of their spines*, are often found attached other shells, as shown in the following figures. Now, these shells must have been dead, *but not yet covered with deposit* during the whole time the attached shell was growing. As a general rule, in fragmental rocks the finest

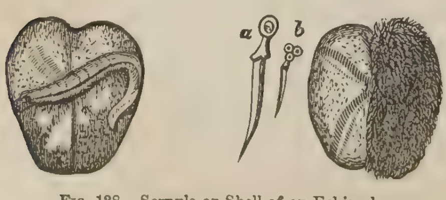


Fig. 188.—Serpula on Shell of an Echinoderm.

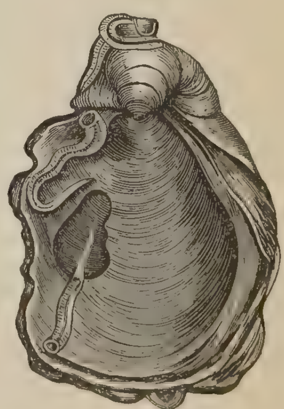


Fig. 189.—Serpulæ on Interior of a Shell.

materials, such as clay and mud, have been deposited very slowly, while coarse materials, such as sand, gravel, and pebbles, have been deposited rapidly. Limestones, being generally formed by the accumulation of the calcareous remains of successive generations of organisms, living and dying on the same spot, must have accumulated with extreme slowness. The same is true of infusorial earths.

It is necessary, therefore, to bear in mind that all stratified rocks were formed in previous epochs by the *regular* operation of agents similar to those in operation at present, and not by irregular or cataclysmic action, as supposed by the older geologists. Thus, *cæteris paribus*, the thickness of a rock may be taken as a rude measure of the time consumed in its formation.

III. Stratified Rocks were originally nearly horizontal.—The horizontal position is naturally assumed by all sediments, in obedience to the law of gravity. When, therefore, we find strata highly inclined or folded, we conclude that their position has been subsequently changed. It must not be supposed, however, that the planes which separate strata were originally perfectly horizontal, or that the strata themselves were of unvarying thickness, and laid atop of each other like the sheets of a ream of paper. On the contrary, each stratum, when first deposited, must be regarded as a widely expanded *cake*, thickest in the middle and thinning out at the edges, and interlapping there with other similar cakes. Fig. 140 is a diagram showing the mode of interlapping.

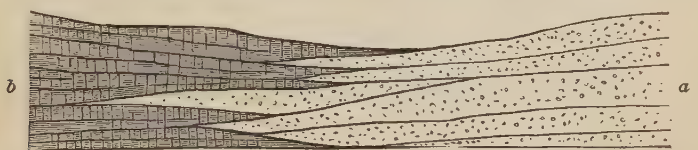


FIG. 140.—Diagram showing Thinning out of Beds: *a*, sandstones and conglomerates; *b*, limestones.

The extent of these cakes depends upon the nature of the material. In fine materials strata assume the form of extensive thin sheets, while coarse materials thin out more rapidly, and are therefore more local.

The most important apparent exception to the law of original horizontality is the phenomenon of *oblique or cross lamination.* This kind of lamination is formed by rapid, shifting currents, bearing abundance of coarse materials, or by chafing of waves on an exposed beach. Many examples of similar lamination are found in rocks of previous epochs. Figs. 141 and 142 represent such examples. In some cases oblique lamination may be mistaken for highly-inclined strata; careful examination,

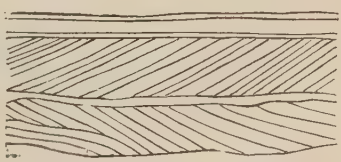


FIG. 141.—Oblique Lamination.

however, will show that the strata are not parallel with the laminæ. The strata were originally (and in the cases represented in the figures are *still*) horizontal, while the laminæ are oblique.

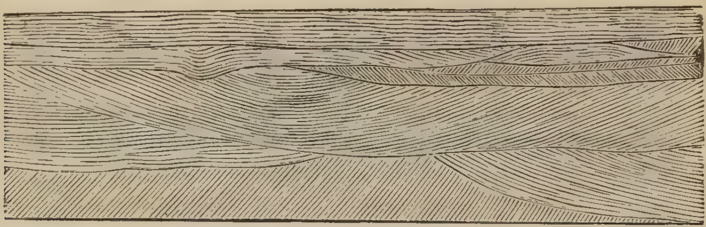


FIG. 142.—Section on Mississippi Central Railroad at Oxford (after Hilgard): Oblique Lamination.

Elevated, Inclined, and Folded Strata.—We may assume, therefore, that strata were originally horizontal at the bottom of seas and lakes; and, therefore, when we find them in other places and positions, they have been subsequently disturbed. Now, we actually do find strata in every conceivable position and place; sometimes they retain their original horizontality, but are raised above their original level; sometimes they have been squeezed by lateral pressure, and thrown into the most intricate contortions (Figs. 143, 144, and 145); sometimes whole groups of strata many thousand feet thick are thrown into huge parallel folds or wrinkles, forming parallel ranges of mountains (Figs. 146 and 147); sometimes by these movements the strata are broken, and one side of the fissure slips up, while the other side drops down, thus producing what is called a *fault* (*see* page 230). But whether simply elevated, or also contorted, or broken and slipped, in nearly all cases large portions of the original strata are carried away by erosion, and they are left in patches and basins, or with their upturned edges exposed on the surface, as shown

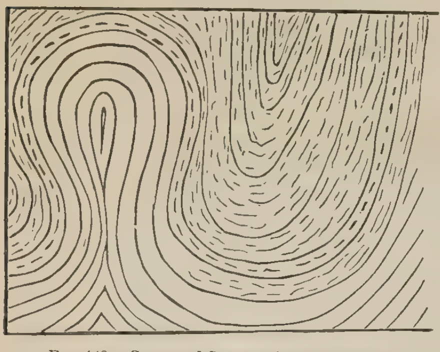


FIG. 143.—Contorted Strata (after Hitchcock).

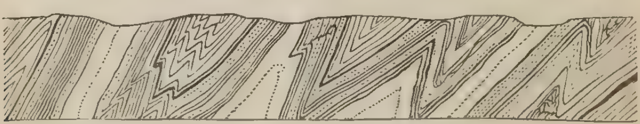


FIG. 144.—Contorted Strata (from Logan).

Fig. 145.—Contorted Strata.

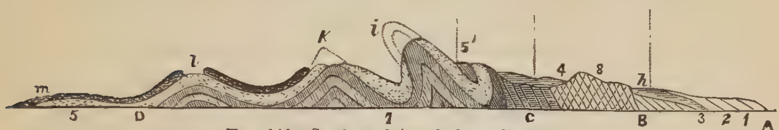


Fig. 146.—Section of Appalachian Chain.

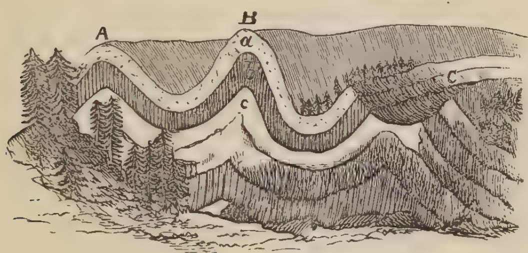


Fig. 147.—Section of the Jura Mountains.

Fig. 148.

in Figs. 148, 149, and 150, in which the dotted lines show the part removed. We are thus enabled to examine strata which would otherwise have remained forever hid from us. The exposure of the edges of strata on the surface by erosion is called *outcrop.* There are certain terms in constant use by geologists which must be explained in this connection.

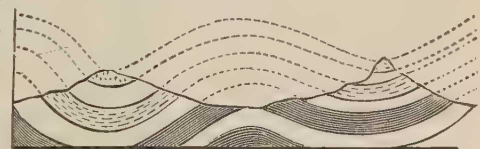


Fig. 149.

Dip and Strike.—The inclination of strata to an horizontal plane is

called the *dip*. Thus, in Fig. 152, the strata dip 25° *toward the south.*

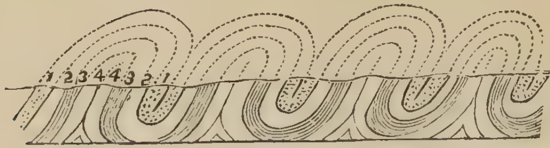


FIG. 150.

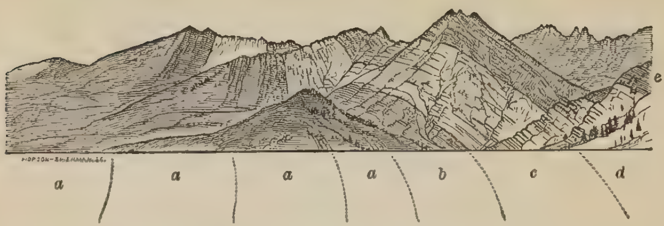


FIG. 151.—Upturned and Eroded Strata, Elk Mountains, Colorado (after Hayden).

The dip may vary from 0° to 90°, from horizontality to verticality. Fig. 153 gives an example of vertical strata. When in strong foldings the strata are pushed over beyond the perpendicular, as in Fig. 150, we have what is called an *overturn dip.* When strata dipping regularly are exposed on their edges, as in Fig. 152, their *thickness* may be easily calculated. If we measure the distance a b and the angle of dip c a b, then c b, the thickness of the strata, is equal to the sine of the angle of dip, multiplied by the distance a b ($R = 1 : a\ b :: \text{sine}\ c\ a\ b : c\ b$ and $c\ b = a\ b \times \text{sine}\ c\ a\ b$).

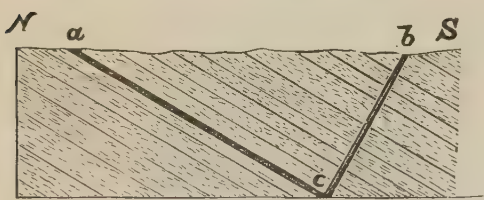


FIG. 152.

The angle of dip is obtained by means of an instrument called a *clinometer* (Fig. 154). The most convenient form is a pocket compass containing a pendulum to indicate the angle of dip.

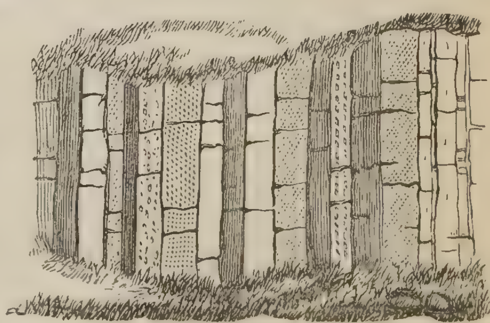


FIG. 153.—Vertical Strata.

It is rarely the case that the geologist is able to get a complete *natural* section of an exten-

sive series of strata. He is usually, therefore, compelled to *construct* a more or less *ideal* section from the examination of outcrops and partial sections wherever he can find them.

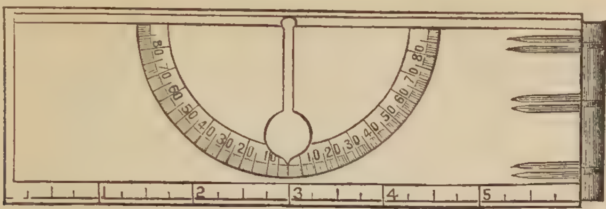


FIG. 154.—Clinometer.

The *strike* is the line of intersection of strata with an *horizontal* plane, or the direction of the outcrop of strata on a *level* surface. It is always at right angles to the dip. If the dip is toward the north or south, the strike is east and west. If the strata are plane, the strike is a straight line, but in folded strata the strike may become very sinuous. The *outcrop* of strata upon the actual surface is often extremely irregular, since this is affected not only by the foldings of the strata, but by the inequalities of surface produced by erosion. The intricate outcrop of rocks, under these circumstances, can only be understood by actual examination in the field or by the use of models.[1] A comparatively simple case of such outcrop is given in Fig. 155, and the manner in which the rocks are folded and eroded is shown in the section Fig. 156.

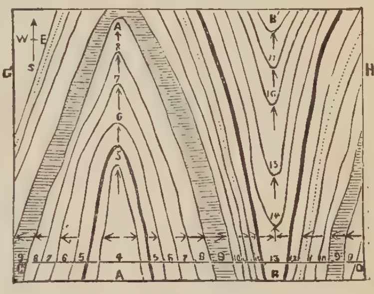


FIG. 155.—Plan of Undulating Strata.

Anticlines and Synclines.—Folded strata, of course, usually dip alternately in opposite directions, forming alternate ridges and hollows, or saddles and troughs (Fig. 156). A line *from* which the strata dip in opposite directions on the two sides is called an anticlinal axis, or simply an *anticline;* a line *toward* which the strata dip in opposite directions on the two sides is called a synclinal axis, or a *syncline.* The *strata*, in the case of an anticline, always form a ridge, and in the case of a syncline a trough; but, in the *actual surface*, this is often entirely

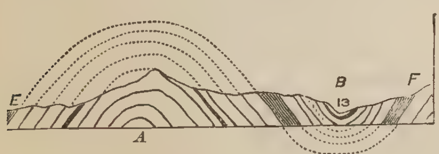


FIG. 156.—Section of Undulating Strata.

[1] Sopwith's Geological Models.

reversed by *erosion*, so that the synclines become the ridges and the anticlines the hollows or valleys. Fig. 149 represents a section in which the anticlines or original ridges have become valleys, while the synclines or original valleys have become mountain-ridges. Examples of synclinal mountains and anticlinal valleys are by no means uncommon. In both anticlines and synclines the strata are repeated on each side of the axis.

Monoclinal Axes.—Sometimes strata over large areas are lifted bodily upward with little change of inclination, while over contiguous areas they are dropped down, the two areas being connected by a sharp bend of the strata instead of a fault. Such a bend is called a monoclinal fold or axis (Fig. 157). Monoclinal folds pass by insensible gra-

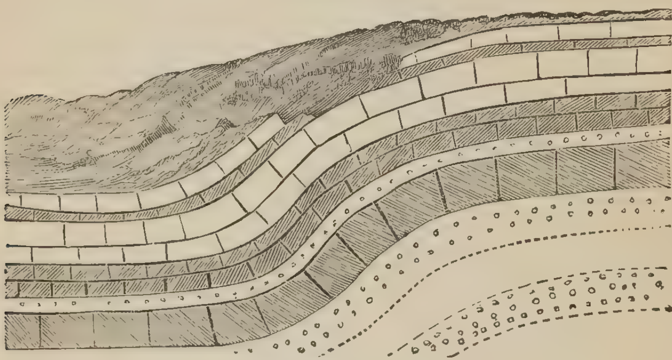


FIG. 157.—Monoclinal Fold (from Powell).

dations into faults, and are evidently produced in a similar manner—the degree of flexibility of the strata determining whether the one or the other is formed. In the plateau of Colorado, where monoclinal folds are common, they may be traced into faults. Fig. 157 is taken from this region.

Unconformity.—We have seen (page 175) that land-surfaces are always composed of eroded, and usually of tilted, strata. We have also seen (pages 127–130) that land-surfaces are now in some places sinking and becoming sea-bottoms, while in others sea-bottoms are rising and becoming land-surfaces. The same thing has happened in every geological epoch. Now, whenever an eroded land-surface sinks below the water and receives sediments, these sediments will lie in horizontal layers upon the upturned edges, and filling up the erosion hollows of the previous strata. If, now, the two series of strata be again elevated into land-surface, and exposed to the inspection of the geologist, the relation of the two series to one another will be represented by the following sections (Figs. 158 and 159). When one series of strata rests thus on

the eroded surface or edges of another series, the two series are said to be *unconformable*. Of course, the whole series may be again elevated, tilted, and eroded, making the phenomena far more complex than here

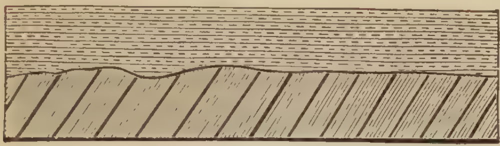


FIG. 158.—Unconformity.

represented. By far the most common case is that of Fig. 158, in which the upper series rests on the upturned edges of the lower series, and there is therefore a *want of parallelism* between the two series; and

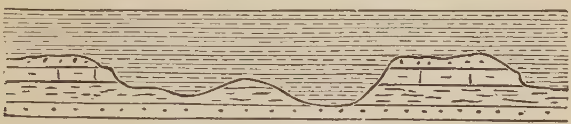


FIG. 159.—Unconformity.

the term unconformity is usually defined as a want of parallelism; but it should be applied also to cases like Fig. 159, where there is no want of parallelism.

Conformable strata indicate a period of comparative *repose*, during which sediments were quietly deposited. Unconformity indicates a period of *disturbance*, during which the strata were elevated into a land-surface, subjected to erosion, and again subsided to receive other sediments. A section like Fig. 158 or 159, one of the commonest in structural geology, indicates two periods of repose and one of disturbance. The lapse of time in the periods of repose is represented by the strata; the lapse of time in the period of disturbance is represented by the *erosion*. Every case of unconformity, therefore, indicates *a gap in the history of the earth*—a period unrecorded by strata *at that place.*

Formation.—A group of conformable strata often constitutes what geologists call a *formation.* Unconformable strata usually belong to different formations. These divisions, however, are founded also upon the character of the contained fossils. This subject will be more fully explained hereafter.

Cleavage Structure.[1]

We have thus far spoken only of the original and universal structure of stratified rocks, together with the tiltings, foldings, and erosion, to

[1] This structure is usually treated under metamorphic rocks, as a kind of metamorphism; but it is found in rocks which have not undergone ordinary metamorphic changes, and it is produced by an entirely different cause.

which they have been subjected. There is, however, often found in stratified rocks a *superinduced* structure which simulates, and is often mistaken for, stratification. It is called *cleavage structure*, or (since it is usually found in slates) *slaty cleavage.* This subject has recently attracted much attention, and is an admirable example of the successful application of physics to the solution of problems in geology.

Cleavage may be defined as the easy splitting of any substance in planes parallel to each other. Such definite splitting may result, in different cases, from entirely different causes. For example (*a*), under the influence of the sorting power of water, sedimentary materials may be so arranged as to give rise to easy splitting along the planes of lamination. Many rocks may be thus split into large coarse slabs called flag-stones, and are used for paving streets, or even sometimes as roofing-slates. This may be called *flag-stone cleavage*, or lamination cleavage. Again (*b*), the arrangement of the ultimate molecules of a mineral under the influence of molecular or crystalline forces gives rise to an exquisite splitting along the planes parallel to the fundamental faces of the crystal. This is called *crystalline cleavage.* Again (*c*), the arrangement of the wood-cells under the influence of vital forces gives rise to easy splitting of wood in the direction of the silver-grain. This may be called *organic cleavage.*

Now, in certain slates and some other rocks is found a very perfect cleavage on a stupendous scale. Whole mountains of strata may be cleft from top to bottom in thin slabs, along planes parallel to each other. The planes of cleavage seem to have no relation to the strata, but cut through them, maintaining their parallelism, however the strata may vary in dip (Fig. 160). Usually the cleavage-planes are highly inclined, and often nearly perpendicular. It is from the cleaving of such

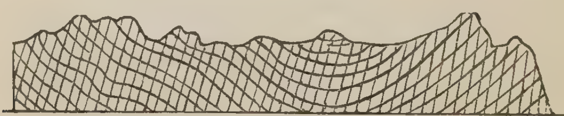


Fig. 160.—Cleavage-Planes cutting through Strata.

slates that roofing-slates, ciphering-slates, and blackboard-slates are made. This remarkable structure has long excited the interest of geologists, and many theories have been proposed to explain it.

On cursory examination of such rocks, the first impression is, that the cleavage is but a very perfect example of flag-stone or lamination cleavage—that the cleavage-planes are in fact stratification-planes, and that we have here an admirable example of finely laminated rocks which have been highly tilted and then the edges exposed by erosion. Closer examination, however, will generally show the falseness of this view.

Fig. 161 represents a mass of slate in which three kinds of structure are distinctly seen, viz., *joint faces, A, B, C, J, J; stratification-planes,*

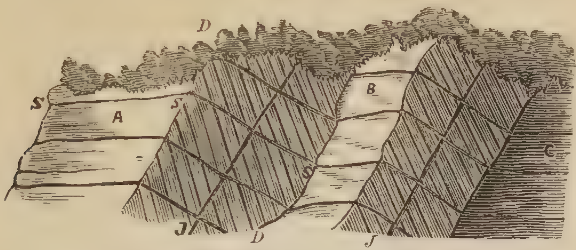


FIG. 161.—Strata, Cleavage-Planes, and Joints.

S S S, gently dipping to the right; and *cleavage-planes*, highly inclined, *D D*, cutting through both. Cleavage-planes are therefore not stratification-planes.

Again, it has been compared to crystalline cleavage, on a huge scale. It has been supposed that electricity traversing the earth in certain directions, while certain rocks were in a semi-fluid or plastic state through heat, arranged the particles of such rocks in a definite way, giving rise to easy splitting in definite directions. In support of this view it was urged that cleaved slates are most common in metamorphic regions; and metamorphism, as we shall see hereafter (p. 223, *et seq.*), indicates the previous plastic state of rocks, which is a necessary condition of the rearrangement of the particles by electricity. The great objections to this theory are—1. That the cleavage is not like crystalline cleavage, between ultimate molecules, and therefore perfectly smooth, but between discrete and quite visible granules; and, 2. That although the phenomenon is indeed most common in metamorphic rocks, yet metamorphism is by no means a necessary condition; on the contrary, when the real necessary conditions are present, the less the metamorphism the more perfect the cleavage.

It is evident, therefore, that slaty cleavage is not due to any of the causes spoken of above. It is not flag-stone cleavage, nor crystalline cleavage, and of course cannot be organic cleavage.

Sharpe's Mechanical Theory.—The first decided step in the right direction was made by Sharpe. According to him, *slaty cleavage is always due to powerful pressure at right angles to the planes of cleavage, by which the pressed mass has been compressed in the direction of pressure and extended in the direction of cleavage.* This theory may be now regarded as completely established by the labors of Sharpe, Sorby, Haughton, Tyndall, and others. We will give a few of the most important observations which establish its truth.

(*a.*) *Distorted Shells.*—Many cleaved slates are full of fossils. In

such cases the fossils are always crushed and distorted as if by powerful pressure, their diameters being shortened at right angles to the cleavage, and greatly increased in the direction of the cleavage-planes. The following figures (Fig. 162) are examples of distortion by pressure. In

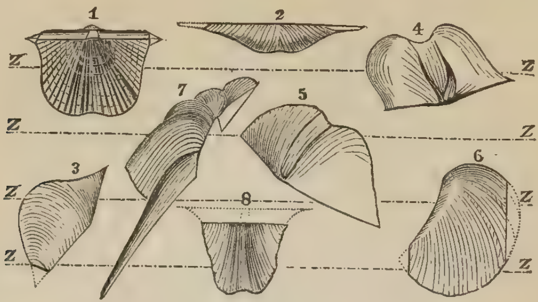


Fig. 162.—Distorted Fossils (after Sharpe).

Fig. 162, Z Z gives the direction of the planes of cleavage; Figs. 1, 2, 3, 4, represent one species; 5, 6, 7, 8, another. In Fig. 163 still another species is represented in the natural and distorted forms.

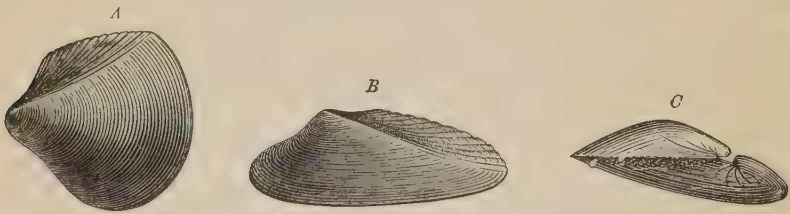


Fig. 163.—Cardium Hillanum: *A*, natural form; *B* and *C*, deformed by pressure.

(*b.*) *Association with Foldings.*—Cleavage is always associated with *strong* foldings and contortions of the *strata*. The folding of the strata

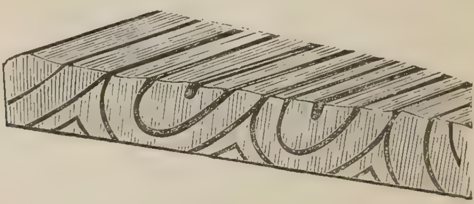


Fig. 164.—Cleavage-Planes intersecting Strata.

is produced by *horizontal* pressure; the strike of the strata, or the direction of the anticlinal and synclinal axes, being of course at right

angles to the direction of pressure. Now, if cleavage is produced by the same pressure which folded the strata, then in this case we ought to find the cleavage-planes highly inclined, and their strike parallel with the strike of the strata; and such we find is usually the fact. In Fig. 164 the heavy lines represent the strata and the light lines the cleavage-planes, both outcropping on a nearly level surface, and parallel to each other.

(*c.*) *Association with Contorted Laminæ.*—The last evidence was taken from foldings on a grand scale of the crust of the earth; but even fine lines of lamination are often thrown into intricate foldings by squeezing together in the direction of the lamination-planes. In such case, of course the cleavage ought by theory to be at right angles to the original direction of the lamination, and in such direction we actually find them. Fig. 165 represents a block of rock in which three lamination-lines are visible. The lower one, *f d*, consists of coarse sand which could not mash, and therefore has been thrown into folds. As the specimen stands in the figure, the pressure has been horizontal; the perpendicular lines represent the position of the cleavage-planes. Fig. 166 represents a beautiful specimen of laminated slate, in which the lamination-planes have been thrown into folds by pressure. The direction of the pressure is obvious. The planes of cleavage are parallel to the face, *c p*, and therefore at right angles to the pressure.

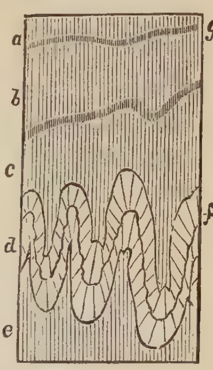


FIG. 165.—Cleavage-Planes (after Tyndall).

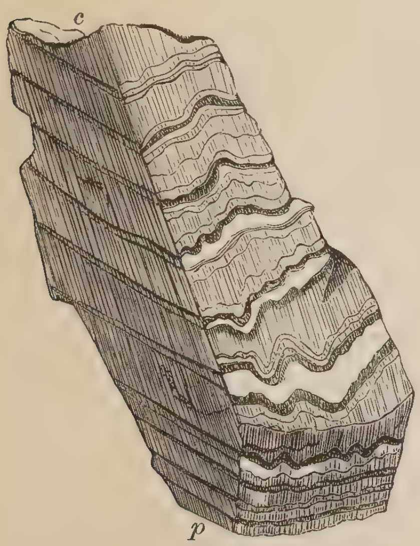


FIG. 166.—A Block of Cleaved Slate (after Jukes).

(*d.*) *Flattened Nodules.*—In some finely-cleaved slates, such as are used for writing-slates, it is common to find small light-greenish, elliptical spots of finer material. In clay-deposits of the present day it is also common to find imbedded little round nodules of finer material. It is probable that the greenish nodules in slates were also rounded nodules of finer clay in the original clay-deposit from which the slate was formed by consolidation. But in cleaved slates these nod-

ules are always very much flattened in the direction at right angles to the cleavage-planes, and spread out in the direction of these planes.

(*e.*) *Apparent Diamagnetism of Cleaved Slates under Certain Conditions.*—If a bar of iron be placed between the poles of a magnet, it will immediately place itself in the line connecting the poles (*axial position*); but if a bar of bismuth be similarly placed, it will assume a position at right angles to the axial line (*equatorial position*). In the former case the ends of the bar are attracted by the poles; in the other they are repelled. Bodies which, like iron, assume the axial position, are called *paramagnetic;* bodies which, like bismuth, assume the equatorial position, are called *diamagnetic*. But Tyndall has shown[1] that by strong compression a paramagnetic substance may be made to as-

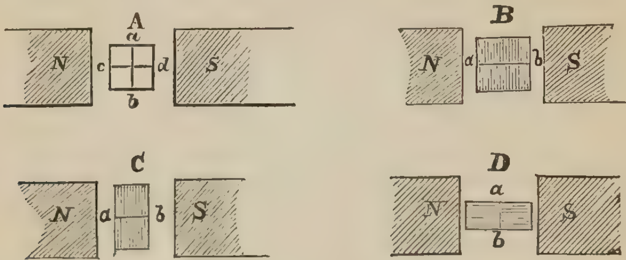


FIG. 167.—Illustrating Behavior of Cleaved Slates in the Magnetic Field.

sume an equatorial or diamagnetic position. If a cube of iron be placed between the poles *N* and *S* of a magnet (Fig. 167, *A*), the cube will be indifferent as to position, since the attraction along any two lines, *a b*, *c d*, at right angles to one another, will be equal. But if *iron-filings* be made into a mass with gum, and then subjected to strong compression in one direction, and from the pressed mass a cube be cut, this cube, placed in the magnetic field, is no longer indifferent, but sets with its line of greatest compression, *a b* (Fig. 167, *B*), axial; the attraction along this line being greater than along any other line, because the number and proximity of the particles are greater along this line. And so much greater is the magnetic attraction along this line than along any other, that this diameter may be cut away to a considerable extent, so as to make a short bar, and still the line *a b* will maintain its axial position (Fig. 167, *C*), and the bar will seem to be diamagnetic, i. e., its long diameter will be equatorial; not, however, because its ends are repelled, but because the attraction along the shorter diameter *a b* is greater than along the long diameter. If, therefore, the cutting-down of the diameter *a b* be continued, finally the influence of length will prevail over that of com-

[1] *Philosophical Magazine*, third series, vol. xxxvii., p. 1, and fourth series, vol. ii., p. 165.

pression, and the bar will assume its true axial position (Fig. 167, *D*). Now, Tyndall, while experimenting upon the magnetic properties of various bodies,[1] found that a short bar of cleaved slate, with its longer diameter in the plane of cleavage, when placed in the magnetic field, takes the equatorial position; although, if the bar be slender, it at once shows its paramagnetism by assuming the axial position. In other words, cleaved slate behaves exactly as if it was a paramagnetic powder pressed in the direction at right angles to the cleavage-planes.

(*f.*) *Experimental Proof.*—Finally, experiments by Sorby and by Tyndall show that clay (the basis of slates), when subjected to powerful pressure, exhibits always a cleavage, often a very perfect cleavage, at right angles to the line of pressure.

Physical Theory.—Cleavage is certainly produced by pressure, but the question still remains: How does pressure produce planes of easy splitting at right angles to its own direction? What is the physical explanation of cleavage?

Sorby's Theory.[2]—Mr. Sorby's view is that all cleaved rocks consisted, at the time when this structure was impressed upon it, of a plastic mass, with *unequiaxed foreign particles* disseminated through it; and that *by pressure the unequiaxed particles were turned so as to bring their long diameters in a direction more or less nearly at right angles to the line of pressure, and thus determined planes of easy fracture in that direction.* Usually, as in slates, the plastic material is clay, and the unequiaxed particles are mica-scales. Let *A*, Fig. 168, represent a cube of clay with mica disseminated. If such a cube be dried and broken, the fracture will take place principally along the surfaces of the mica, which may therefore be seen glistening on the uneven surface of the fracture; but if the cube, while still plastic, be pressed into a flattened disk, then the scales are turned with their long diameters in the direction of extension and at right angles to the line of pressure, as in *B*, Fig. 168, and the planes of easy fracture, being still determined by these surfaces, will be in that direction.

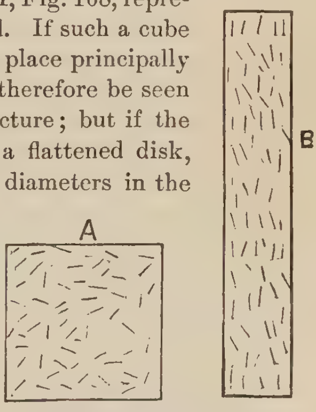


Fig. 168.—Illustrating Sorby's Theory of Slaty Cleavage (after Sorby).

In proof of this view, Mr. Sorby mixed clay with mica-scales or with oxide-of-iron scales, and, upon subjecting the mass to powerful compression and drying, he always found a perfect cleavage at right angles to the line of pressure. Furthermore, by microscopic examination he found that both in the pressed clay and in the cleaved slates the mica-scales lay in the direction of the cleavage-planes.

[1] *Philosophical Magazine*, 4th series, vol. v., p. 303. [2] Ib., 2d series, vol. xi., p. 20.

Although cleavage is most perfect in slates, yet other rocks are sometimes affected with this structure. In a specimen of cleaved limestone, Sorby found under the microscope unequiaxed fragments of broken shells, corals, crinoid stems, etc. (organic particles), in a homogeneous limestone-paste, lying with their long diameters in the direction of cleavage. Originally the limestone was a lime-mud with (he supposes) unequiaxed organic particles disseminated. In some cases, however, Sorby recognized the very important fact that the organic fragments, which were encrinal joints, had been *flattened by pressure*—had *changed their form* instead of their position. *A*, Fig. 169, gives a section of the mass in the supposed original condition, and *B* the condition after pressure. This observation contained the germ of the theory proposed by Tyndall.

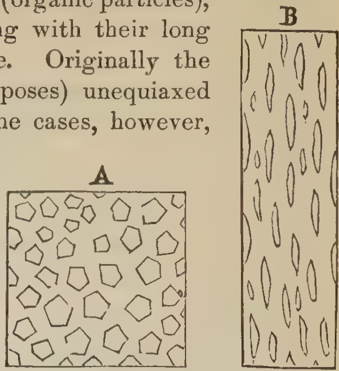


Fig. 169.—Illustrating Sorby's Theory of Slaty Cleavage (after Sorby).

Tyndall's Theory.[1]—Tyndall was led to reject Sorby's theory by the observation that cleavage structure was not confined to masses containing unequiaxed particles of any kind, but, on the contrary, the cleavage is more perfect in proportion as the mass is free from all such particles. Clay, deprived of the last trace of foreign particles by the sorting power of water, when pressed, cleaved in the most perfect manner. Common beeswax, flattened by powerful pressure between two plates of glass and then hardened by cold, exhibits a most beautiful cleavage structure. Almost any substance—curds, white-lead powder, plumbago—subjected to powerful pressure, exhibits to some extent a similar structure. Tyndall explains these facts thus: Nearly all substances, except vitreous, have a granular or a crystalline structure, i. e., consist *entirely* of discrete granules or crystals, with surfaces of easy fracture between them. When such substances are broken, the fracture takes place between the crystals or granules, producing a rough crystalline or granular surface, entirely different from the smooth surface of vitreous fracture. Marble, cast-iron, earthenware, and clay, are good examples of crystalline and granular structure. Now, if a mass thus composed yield to pressure, every constituent granule is flattened into a scale, and the structure becomes *scaly;* and as the surfaces of easy fracture will still be between the constituent scales, we have cleavage at right angles to the line of pressure. A mass of iron, just taken from the puddling-furnace and cooled, exhibits a *granular* structure; but if drawn out into a bar, each granule is extended into a thread, and the structure becomes *fibrous;*

[1] *Philosophical Magazine*, 2d series, vol. xii., p. 35.

or if rolled into a sheet, each granule is flattened into a scale, and we have a *cleavage structure.*

There can be little doubt that this is the true explanation of slaty cleavage. The change of form which, as we have seen, has taken place in the fossil-shells, encrinal joints, and rounded nodules, has affected every constituent granule of the original earthy mass, so that the structure becomes essentially scaly instead of granular; the cleavage being between the constituent scales. Sorby, it is true, in his observations on cleaved limestones, recognized the true cause of cleavage, viz., the *change of form* of discrete particles; but he regarded this as subordinate to change of position. Besides, the particles of Sorby were *foreign*, which Tyndall has shown to be unnecessary; while the particles of Tyndall are *constituent.*

Geological Application.—It may be considered, therefore, as certain that cleaved slates have assumed their peculiar structure under the influence of powerful pressure at right angles to the cleavage-planes, by which the whole squeezed mass is mashed together in one direction and extended in another. Taking any ideal sphere in the original unsqueezed mass: after mashing the diameter in the line of pressure has been shortened, the diameter in the line of cleavage-*dip* has been correspondingly extended, and the diameter in the line of cleavage-strike unaffected, since extension of this diameter in any place must be compensated by shortening in a contiguous place right or left; so that the original sphere has been converted into a greatly-flattened ellipsoid of three unequal diameters. The *amount* of compression and extension may be estimated in the case *a* by the amount of distortion of shells of known form (Figs. 162 and 163); in the case *c* by a comparison of the transverse diameter with the length of the folded line *f d* (Fig. 165); in the case *d* by the relation between the diameters of the elliptic spots. By these means, but principally by the first, Haughton[1] has estimated that the original sphere has been changed into an ellipsoid, whose greatest and shortest diameters are to each other, in some cases, as 2 : 1, in others as 3 : 1, 4 : 1, 6 or 7 : 1, 9 : 1, and in some even 11 : 1. The average in well-cleaved slates, according to Sorby, is about 6 : 1. Now, since this ratio is the result partly of compression and partly of extension, it is evident that either the compression alone or the extension alone would be the square roots of these ratios. Therefore, we may assume the average compression as $2\frac{1}{2} : 1$, and the average extension as $1 : 2\frac{1}{2}$.

It is impossible to over-estimate the geological importance of these facts. Whole mountains of strata, whole regions of the earth's crust, are cleaved to great and unknown depths, showing that the crust has been subjected to an almost inconceivable force, squeezing it together in an horizontal direction and swelling it upward. This upward swell-

[1] *Philosophical Magazine*, fourth series, vol. xii., p. 409.

ing, or thickening of the strata by lateral squeezing, is a probable cause of gradual elevation of the earth's crust, which has not been noticed by geologists. We will speak again of this important subject in our discussion of mountain-formation.

There are reasons for believing that the squeezing did not take place, and the structure was not formed, while the strata were in their original condition of plastic sediment, but after they had been consolidated into rock and the contained fossils had been completely petrified, otherwise the shells must have been broken by the pressure. Yet, on the other hand, some degree of plasticity seems absolutely necessary to account for so great a compression in one direction and extension in another without disintegration of the mass. It seems most probable that at the time the structure was produced these rocks were deeply buried beneath other rocks and in a somewhat plastic state, through the influence of heat in the presence of water. Afterward, they were exposed by erosion.

Nodular or Concretionary Structure.

In many stratified rocks are found nodules of various forms scattered through the mass or in layers parallel to the planes of stratification. Like slaty cleavage, this structure is the result of internal changes subsequent to the sedimentation; for the planes of stratification often pass directly through the nodules (Figs. 170 and 171). The flint nodules of

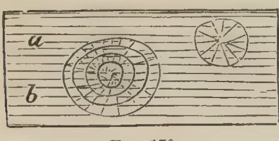


FIG. 170.

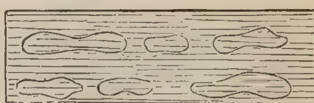


FIG. 171.

the chalk, and the clay iron-stone nodules of the coal strata and hydraulic lime-balls, common in many clays, are familiar illustrations of this structure.

Cause.—Nodular concretions seem to occur whenever any substance is diffused in small quantities through a mass of entirely different material. Thus, if strata of sandstone or clay have small quantities of carbonate of lime or carbonate of iron diffused through them, the diffused particles of lime or iron will gradually, by a process little understood, segregate themselves into more or less spherical or nodular masses, in some cases almost pure, but generally inclosing a considerable quantity of the material of the strata. In this manner lime-balls and iron-ore balls and nodules, so common in sandstones and clays, are formed. In like manner, the flint nodules of the chalk were formed by the segregation of silica, originally diffused in small quantities through the chalk-

sediment. Very often some foreign substance forms the nucleus about which the segregation commences. On breaking a nodule open, a shell or some other organism is often found beautifully preserved. These nodules, therefore, are a fruitful source of beautiful fossils. In most cases, probably in all cases, the segregating substance must have been to some extent soluble in water pervading, or suspensible in water percolating, the stratum. Sometimes the nodules run together, forming a more or less continuous stratum. In such cases, the segregating material is more impure.

FIG. 172.

Forms of Nodules.—The typical and most common form is *globular.* This is well seen in lime-balls and iron-balls. Sometimes these balls are solid, sometimes they have irregular cracks in the centre (Fig. 172), sometimes they have a radiated structure (Fig. 173), sometimes they are hollow like a shell (this is common in iron-balls). They vary in size from that of a pea to six and eight feet in diameter. Often, however, instead of the spherical form, they take on various and strange and

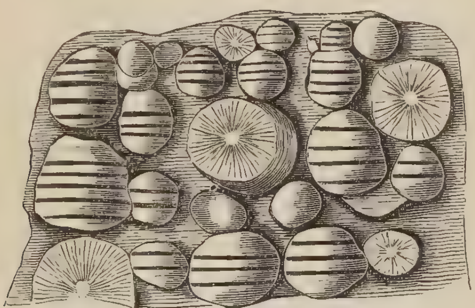


FIG. 173.—Dolomite containing Concretions, Sunderland (after Jukes).

fantastic shapes (Fig. 174), sometimes like a dumb-bell, sometimes a flattened disk, sometimes a ring, sometimes a flattened ellipsoid, regularly seamed on the surface like the shell of a turtle (turtle-stones). They are often mistaken by unscientific observers for fossils.

Kinds of Nodules found in Different Strata.—In sandstone strata the nodules are commonly carbonate of lime or oxide of iron (lime or iron balls). In *clay strata* they are carbonate of lime or carbonate of iron (clay iron-stone of coal strata), or a mixture of these (Roman cement nodules of the London clay).

In limestone the nodules are always silica, and conversely silica nodules are peculiar to limestone. The flint nodules of the chalk are remarkable for being arranged in planes parallel to the planes of strati-

FIG. 174.—Limestone Strata containing Concretions.

fication (Fig. 175). Sometimes the siliceous matter segregates in continuous strata of siliceous limestone (Fig. 176).

In the cases thus far spoken of, the nodules are scattered through the mass of the strata or arranged in planes parallel to planes of stra-

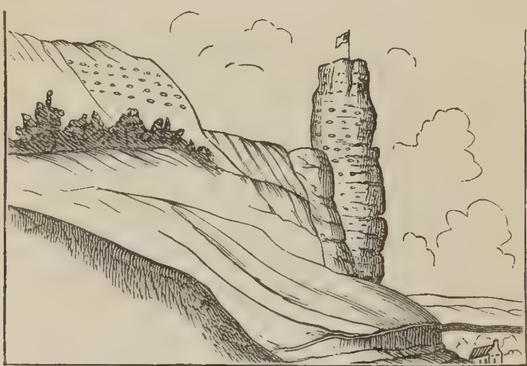


FIG. 175.—Chalk-Cliffs with Flint Nodules.

tification. But in some cases the whole mass of the rock assumes a concretionary or concentric structure (Fig. 177). The cause of this is still more difficult to explain.

FOSSILS: THEIR ORIGIN AND DISTRIBUTION.

Stratified rocks, as we have already seen, are sediments accumulated in ancient seas, lakes, deltas, etc., and consolidated by time. As now, so *then*, dead shells were imbedded in shore-deposits; leaves and logs of

high land-plants, and bones of land-animals, were drifted into swamps and deltas and buried in mud; and tracks were formed on flat, muddy shores by animals walking on them. These have been preserved with more or less change, and are even now found in great numbers inclosed in stratified rocks. They are called *fossils.* A fossil, therefore, is any evidence of the former existence of a living being. Fossils are the remains of the fauna and flora of previous geological epochs. Their presence is the most constant characteristic of stratified rocks.

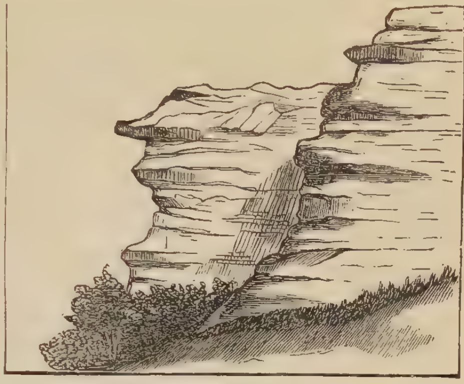


Fig. 176.—Chalk-Cliffs.

The Degrees of Preservation are very various.—Sometimes only the tracks of animals, or impressions of leaves of plants, are preserved. More commonly the bones or shells, or other hard parts of animals, are

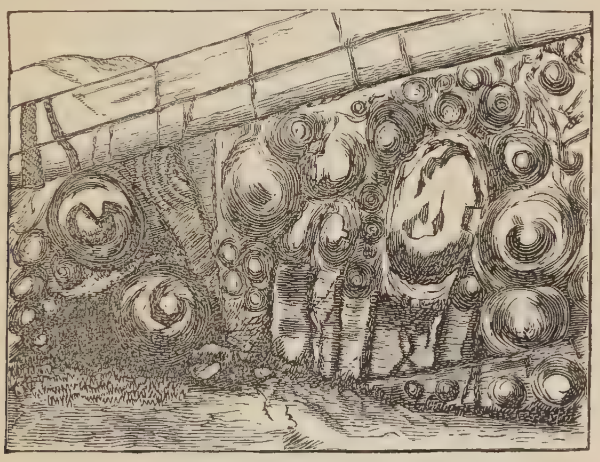


Fig. 177.—Coal-measure Shale, weathering into Spheroids.

preserved with various degrees of change. Sometimes even the soft and more perishable tissues are preserved. We will treat of these degrees under three principal heads:

1. *Decomposition prevented and the Organic Matter more or less completely preserved.*—Cases of this kind are usually found in comparatively *recent* strata, and imbedded either in *frozen soils,* or in *peat,* or in *stiff clays;* although some cases of partial preservation of the or-

ganic matter are found even in old rocks. Extinct elephants have been found frozen in the river-bluffs of Siberia so perfectly preserved that dogs and wolves ate their flesh. Skeletons of men and animals are found in peat-bogs and stiff clays of a comparatively recent formation, the organic matter of which is still preserved. In clays of the Tertiary period the imbedded shells still retain the epidermis, and even in the Lias (mesozoic) shells are found retaining the nacreous lustre. Coal is vegetable matter changed but not destroyed. It is found in almost every formation, even down to the oldest. Every degree of change may be traced in different specimens of fossil wood, between perfect wood and perfect coal.

2. *Petrifaction: Organic Form and Structure preserved.*—In the last case the *organic matter* is more or less preserved. In the case now to be described the organic matter is entirely gone; but the *organic form* and the *organic structure* are preserved in mineral matter. This is what is usually called petrifaction or mineralization. The best example of this is *petrified wood.* In a good specimen of petrified wood, not only the external form of the trunk, not only the general structure of the stem—viz., pith, wood, and bark—not only the radiating silver-grain and the concentric rings of growth, are discernible, but even the microscopic cellular structure of the wood, and the exquisite sculpturings of the cell-walls themselves, are perfectly preserved, so that the kind of wood may often be determined by the microscope with the utmost certainty. Yet not one particle of the organic matter of the wood remains. It has been entirely replaced by mineral matter; usually by some form of silica. The same is true of shells and bones of animals; but as shells and bones consist naturally partly of organic and partly of mineral matter, very often it is only the organic matter which is replaced, although sometimes the original mineral matter is also replaced by silica or other mineral substance. The radiating structure of corals or the microscopic structure of teeth, bones, and shells, is often beautifully preserved. This kind of preservation for shells and corals is most common in limestones and clays; for wood, in gravels.

Theory of Petrifaction.—If wood be soaked in a strong solution of sulphate of iron (copperas) and dried, and the same process be repeated until the wood is highly charged with this salt, and then burned, the structure of the wood will be preserved in the peroxide of iron left. Also, it is well known that the smallest fissures and cavities in rocks are speedily filled by infiltrating waters with mineral matters. Now, wood buried in soil soaked with some petrifying material becomes highly charged with the same, and the cells filled with infiltrated matter, and when the wood decays the petrifying material is left, retaining the structure of the wood. But this is not all, for in Nature there is

an *additional process*, not illustrated either by the experiment or by the example of infiltrated fillings. As each particle of organic matter passes away by decay, a particle of mineral matter takes its place, until finally the whole of the organic matter is replaced. Petrifaction, therefore, is a process of *substitution*, as well as interstitial filling. Now, it so happens, probably from the different nature of the process in the two cases, that the interstitial filling always differs, either in chemical composition or in color, from the substituting material. Thus the structure is still visible, though the mass is solid. If Fig. 178 represent a cross-section of three petrified wood-cells, the matter filling the cells (*b*) is always different from the matter forming the cell-wall (*a*).

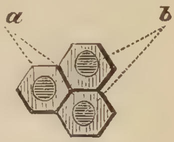


Fig. 178.

The most common petrifying materials are silica, carbonate of lime, and sulphide of iron (pyrites). In the case of petrifaction by pyrites the process is quite intelligible, but the structure is usually very imperfectly preserved. If water containing sulphate of iron ($FeSO_4$) come in contact with decaying organic matter, the salt is deoxidized by the organic matter, the latter passing off as carbonic acid and water, and the former becomes insoluble sulphide (FeS), and is deposited. Now, as each particle of organic matter passes away as CO_2 and H_2O, the molecule of iron sulphate which effected the change is itself changed into insoluble sulphide, and takes its place.

The process of replacement by silica (silicification) is less clear, but it is probably as follows: Silica is found in solution in many waters, being held in this condition by small quantities of alkali present in the waters. In contact with decomposing wood the *alkali is neutralized by the humic, ulmic, and other acids of decomposition, and the silica therefore deposited.*

3. *Organic Form only preserved.*—In the third case organic matter and organic structure are both lost, and only organic form is pre-

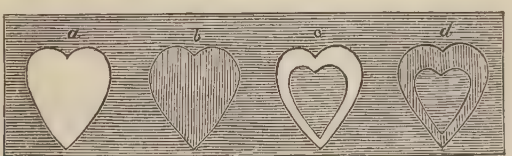


Fig. 179.

served. This kind of fossilization is most commonly seen in shells. It may be subdivided into four subordinate cases, represented in section by *a*, *b*, *c*, and *d* of Fig. 179. In this figure the horizontal lines represent the original sediment which may or may not have consolidated into rock; the vertical lines represent a subsequent filling of different and usually finer material. In *a* we have a *mould of the external form* of

13

the shell preserved in sediment. The shell with the undecayed animal was imbedded, and afterward entirely dissolved away, leaving only the hollow mould. In *b* the same process has taken place, only the mould has been subsequently filled by infiltration of slightly soluble matters. In this case we have both the *mould* and the *cast* of the *external form;* the mould being formed of sediment, and the cast of infiltrated matter. These are always of different materials, i. e., different either in chemical composition or in state of aggregation. In *c* we have a *mould of the external* form in sediment, and a cast of the *internal* form in the *same* material, with an empty space between, having the exact form and thickness of the shell. In this case, the already dead and empty shell

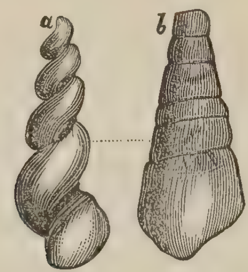


FIG. 180.—*a*, Cast of interior; *b*, natural form.

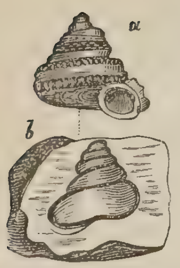


FIG. 181.—*a*, Natural form; *b*, cast of interior and mould of exterior.

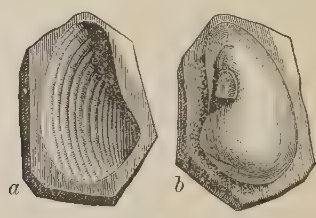


FIG. 182.—Trigonia Longa, showing cast (*a*) of the exterior and (*b*) of the interior of the shell.

was imbedded in sediment, *which also filled its interior;* afterward the shell was removed, leaving an empty space. In *d* this empty space was subsequently filled by infiltration. In shore and river deposits of the present day it is very common to find shells imbedded in, and filled with, sand or mud. In the more recent tertiary rocks shells are commonly found in the same condition precisely; but in the older rocks more commonly the original shell is removed, and the space either left empty or filled by infiltration. Cases *c* and *d* are well represented by Figs. 180, 181, and 182. Cases like *a* and *c* are most commonly found in porous rocks like sandstone; *b* and *d*, especially the latter, are found

in all kinds of rocks. By far the most common *infiltration* fillings are *carbonate of lime* and *silica.*

Often we find impressions of the forms of *small portions only* of the original organism, as of the leaves of trees, or the feet of animals walking on the soft mud of the flat shores of ancient bays. Such tracks were afterward covered up with river or tidal deposit, and thus preserved. On cleaving the rock along the lamination-planes we have on one side a mould and on the other the cast of the *foot.*

Between cases 1 and 2 every stage of gradation may be traced. The amount of change, as a general fact, varies with the age of the rock; but is still more dependent on the kind of rock and the degree of metamorphism (p. 221). In an impermeable rock, like clay, the changes are much more slow than in a porous rock, like sandstone.

Distribution of Fossils in the Strata.

The nature of the fossil species found in rocks is determined partly by the *kind* of rock, partly by the *country* where the rock is found, and partly by the *age* of the rock.

1. **Kind of Rock.**—It has been already stated (p. 162) that the species of lower marine animals vary with the depth. They also vary with the kind of bottom. Thus, along shore-lines and on sand-bottom the species differ from those in deep water and on mud-bottom. Shells are found mostly along shore-lines, corals in opener seas, and foraminifera in deep seas. The same was true in every previous epoch. We might expect, therefore, and do find, that the lower marine fossils of sandstones, shales, and limestones, differ even when these strata belong to the same country and geological epoch. The higher marine animals, such as fishes, cuttle-fish, etc., swimming freely in the sea, are more independent of bottoms, and we find their skeletons and shells equally in all kinds of strata. Land animals perish on land, and their skeletons are drifted into bays, river-deltas, and lakes, and buried there mostly in fresh-water or brackish-water deposits of sand and clay. It is, therefore, in such strata that their remains are commonly found.

2. **The Country where found.**—We have already seen (p. 155) that the faunas and floras of different countries at the present time differ as to species, and often as to genera and families; the difference being generally in proportion to the difference in climate, the physical barriers intervening, and the length of time during which the barriers have existed. The same was true of the faunas and floras of previous epochs, and therefore of the fossils of the same age in different countries. The fossil species of the same epoch in America, and in Europe and in Asia, are not usually identical, although there may be a general resemblance. The geographical diversity, however, is small in the lowest and oldest rocks, and becomes greater and greater as we

pass upward into newer and newer rocks, and is greatest in the fauna and flora of the present day.

3. The Age.—This introduces the subject of the laws of distribution of organisms in *time*, or of fossils vertically in the series of stratified rocks. The subject will be more fully treated in Part III., of which it constitutes the principal portion. We now bring out only so much as is necessary as a basis of classification of stratified rocks.

(*a.*) *Geological Fauna and Flora.*—As we pass from the oldest and lowest rocks upward to the newest and highest, we find that *all* the species, most of the genera, and many of the families, change many times. Now, all the species of animals and plants inhabiting the earth at one time constitute the fauna and flora of that geological time. Geological faunas, therefore, have changed many times. *In a conformable* series of rocks the change from one fossil fauna or flora to another succeeding is always *gradual*, the species of the later fauna or flora gradually replacing those of the earlier. But between two series of unconformable strata the change is sudden and complete—as if one fauna and flora had been suddenly destroyed and another introduced. It must be remembered, however, that unconformity always indicates a great lapse of time unrepresented at the place of observation by strata or fossils. It is therefore probable that the apparent suddenness of the change is only the result of our ignorance of the fauna and flora of the period unrepresented. Nevertheless, as unconformity always indicates changes of physical geography, and therefore of climate, it is probable that in the history of the earth there were periods of great changes, marked by unconformity of strata, during which *changes of species were more rapid*, separated by *periods of comparative quiet*, *marked by conformity*, during which the species were either *unchanged*, or *changed slowly*. Such a period is called a geological period or geological epoch, and the rocks formed during a geological period, or epoch, is called a *formation*.

There are, therefore, two tests of a formation and a corresponding geological period, viz., 1. Conformity of the strata, or *rock-system*, and, 2. General similarity of fossils, or *life-system ;* and two modes of separating formations and corresponding periods, viz., unconformity of the rock-system, and great and sudden change of the life-system. A geological formation, therefore, may be defined as a group of conformable rocks containing *similar fossils*, usually separated from other similar groups containing different fossils by unconformity. A geological period may be defined as a period of comparative quiet, during which the physical geography, climate, and fauna and flora, were substantially the same, usually separated from other similar periods by changes of physical geography and climate, which resulted in changes of fauna and flora. Of these two tests, however, the life-system is

usually considered the most important, and in case of disagreement must control classification.

(*b.*) *Geological Faunas and Floras differ more than Geographical Faunas and Floras.*—If there were no geographical diversity, species of the same age would be identical all over the earth, and therefore it would be easy to determine strata of the same age (geological horizon). On the other hand, if geographical diversity in any age were as great as the diversity between two successive ages, then it would seem impossible to establish a geological horizon. But this law states that the difference between two *successive* faunas is greater than between two *contiguous* faunas. In other words, the species of successive periods, or fossils of successive formations, differ from each other more than species of the same period or fossils of the same formation in different parts of the earth. There is a general similarity in the species of the same period all over the surface of the earth. Hence by comparison of fossils it is possible to determine what strata, in different portions of the earth, belong to the same period (to synchronize strata). The strata *all over the earth*, which were formed at the same time, are said to belong to the same *geological horizon*. Strata of the same horizon are determinable by similarity of fossils with considerable certainty, until we come up to the tertiary rocks. In all the newer rocks, however, the geographical diversity is so great as to interfere seriously with the ability to synchronize by means of comparison of fossils. Another method, therefore, is used for these higher rocks.

(*c.*) *Increasing Likeness to Existing Forms.*—By examining and comparing fossils from the lowest to the highest rocks, it has been observed that there is a steady approach of the fossil faunas and floras to the present faunas and floras, first in the families, then in the genera, and finally in the species. The species of fossil molluscous shells begin to be identical with molluscous species of the present day only in the *tertiary* rocks, and the proportion of identical species steadily increases as we pass upward. Thus in the newer rocks, just where the other method (comparison of fossil faunas with one another) begins to fail, we may synchronize strata of different localities, by comparing their shell fauna with the shell fauna of the present day, in the same localities. *Those are said to be of the same age which contain the same percentage of shells identical with those of the present day.*

Section 2.—Classification of Stratified Rocks.

Geology is essentially a history. Stratified rocks are the leaves on which this history is recorded. The fundamental idea of every classification is therefore *relative age.* The object to be attained in classification is, *first,* to arrange all rocks in chronological order, so that the history may be read as it was written ; and then, *second,* to collect

them into larger and smaller groups, called *systems*, *series*, *formations*, corresponding to the great *eras*, *periods*, *epochs*, of the earth's history. There are several different methods of determining the relative age of rocks:

1. **Order of Superposition.**—It is evident, from the manner in which stratified rocks are formed—viz., by *sedimentation*—that their original position indicates, with absolute certainty, their relative age, the lower being older than the higher. If, therefore, the original position of any series of strata be retained or not very greatly disturbed, and we have a good section, the relative age of the strata which compose the series may be easily determined. But the strata, as we have already seen, have in many cases been crushed and contorted and folded in the most intricate manner, sometimes even turned over; have been broken and slipped, and large masses carried away by erosion, and often so changed by heat and other agents, that their stratification is nearly or quite obliterated. For these reasons it is often very difficult to determine the relative position, and thus to construct an ideal section of the strata of a series of rocks, even in a single locality. Nevertheless, in spite of all these difficulties, the method of superposition is conclusive, and takes precedence of all others whenever it can be applied. In spite of all these difficulties, if the whole geological series were present in any one locality, it would be comparatively easy to construct the geological chronology.

But a series of rocks *in any one locality* cannot give us the whole history of the earth. Since sedimentation only takes place at the bottom of water, those places which were *land-surfaces* during any geological epoch received no deposit, and therefore the strata representing that epoch must be wanting there. Now, as there have been frequent oscillations of land-surfaces and sea-bottoms in past times, similar to those taking place at the present time, we find that in every known local series of strata there exist many and great gaps; so many and so great that the record may be regarded as only fragmentary. Such gaps are usually indicated by unconformity. It is the task of the geologist, by extensive comparison of rocks in all countries, to fill up these gaps, and make a continuous series. The leaves of the *book of Time* are scattered hither and thither over the surface of the earth, and it is the duty of the geologist to gather and arrange them according to their paging. This is done by comparison of rocks of different localities, partly by their lithological character, but principally by the fossils which they contain.

2. **Lithological Character.**—At the present time, in our seas and lakes, deposits are forming composed of sand, clay, mud, and lime, of every kind, in different localities. The same has taken place in previous epochs. Sandstones, limestones, and slates, not differing greatly from

those forming at the present time, except in degree of consolidation, have been formed in every geological period. Lithological character, therefore, is no test of age. In comparing rocks of widely-separated localities, as, for example, the rocks of different continents, difference of lithological character is no evidence of difference of age, nor similarity of lithological character of any value in determining a geological horizon. But, as deposits are now being formed of a similar character over considerable areas, so also we find strata (the deposits of previous epochs), continuous and unchanged in lithological character, over large tracts of country. Therefore, in *contiguous* localities, similarity of lithological character becomes a very valuable means of identifying strata. If, in two localities not too widely separated, we find a similar rock, e. g., a sandstone of similar grain and color, we conclude that they probably belong to the same age, or are, in fact, the same stratum.

3. **Comparison of Fossils.**—This is by far the *best*, and in *widely-separated localities the only*, method of determining the age of rocks. The principle of this method is that every geological epoch has its own fauna and flora by which it may be identified everywhere in spite of those slight differences which result from geographical diversity; and, therefore, similarity of fossils shows similarity of age. There are, however, certain limitations to the application of this method which must be borne in mind:

(*a.*) The lower marine species are much affected by depths and bottoms, and therefore we should expect that sandstone fossils, limestone fossils, and slate fossils, would differ in species even in the same epoch. Again, in lake and delta deposits, the entombed species would probably be entirely different from those of marine deposits. We must be careful, therefore, to compare fossils of rocks formed under similar conditions.

(*b.*) We must also make due allowance for geographical diversity. This, as we have already stated, becomes greater and greater as we pass up the series of rocks. In the *lower* or older rocks the geographical diversity is small; in strata of the same age in different countries the fossils are quite similar, most of the genera and many of the species being undistinguishable. It is therefore comparatively easy, by comparison of fossils, to synchronize the strata and determine the geological horizon. In the *middle* rocks the geographical diversity is greater, but the general similarity is still considerable—the difference between organisms of consecutive epochs (geological faunas and floras) is still much greater than the difference between organisms of the same epoch in different countries (geographical faunas and floras); and, therefore, it is still quite possible, by comparison of fossils, to synchronize the strata. In the *higher* or newer rocks the geographical diversity has become so great that we are compelled to determine age and synchronize strata,

no longer entirely by comparison of fossils of the different localities *with each other*, but also by the comparison of the fossils of each locality with the living species in the same locality. In these rocks we determine relative age by relative percentage of living species, and similarity of age (geological horizon) by similarity of this percentage.

Manner of constructing a Geological Chronology.—The manner in which a geological chronology has actually grown up, under the combined labors of the geologists of all countries, may be briefly stated as follows: First, the *order of superposition*, and therefore the relative ages of the strata composing the rock-series of many different countries, were determined independently; next, by comparison of these, partly by *lithological character*, if the localities are contiguous, and *partly by fossils*, the geologist determines those which are synchronous and those which are wanting in each locality. Thus, out of several local series, by *intercalation*, he constructs a more complete ideal series. In case of doubt, he strives to find places where the doubtful strata come together, and observes their *relative position*. In Fig. 183, *A* and *B* represent

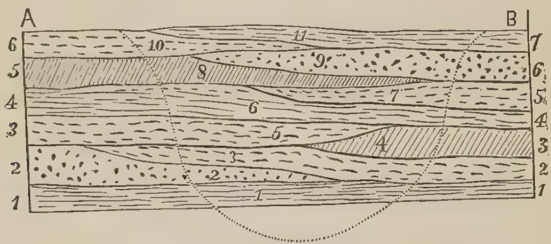


FIG. 183.—Diagram illustrating the Mode of determining the Chronological Order of Strata.

two contiguous localities in which by independent study the relative positions and ages of 6 and 7 strata respectively have been determined. By comparison, the rocks of the two series are found to consist of eleven strata of different ages, some being wanting in the one and some in the other locality. The figure represents the strata as connected and traceable from one locality to the other, but the intervening portions between *A* and *B* may be removed by erosion, as shown by the dotted line, or covered with water. In such case, the actual overlapping cannot be observed, if it ever existed, but the comparison in other respects is the same. In widely-separated localities of course the comparison can only be made by means of fossils. Thus as the examination of the earth's surface progresses, with every new country examined some gaps are filled up, and the series becomes more perfect. Many gaps still remain unfilled. The series will continue to be made more perfect, and the chronology more complete, until the geological examination of the earth-surface is complete.

The second object to be attained by classification is the division and subdivision of the whole series into larger and smaller groups, corresponding to the eras, periods, and epochs of time.

The following is an outline of the classification of Dana, slightly modified. Except in the uppermost part it is carried only as far as periods:

ERAS.	AGES.	PERIODS.		EPOCHS.
5. Psychozoic.	7. Age of Man.	Human,	22	Recent.
4. Cenozoic.	6 The Age of Mammals.	Quaternary,	21	Terrace. Champlain. Glacial.
		Tertiary,	20	Pliocene. Miocene. Eocene.
3. Mesozoic.	5. The Age of Reptiles.	Cretaceous,	19	
		Jurassic,	18	
		Triassic,	17	
2. Palæozoic.	*Carboniferous Age.* 4. The Age of Acrogens and Amphibians.	Permian,	16	
		Carboniferous,	15	
		Sub-carboniferous,	14	
	Devonian. 3. The Age of Fishes.	Catskill,	13	
		Chemung,	12	
		Hamilton,	11	
		Corniferous,	10	
	Silurian. 2. The Age of Invertebrates.	Oriskany,	9	
		Helderberg,	8	
		Salina,	7	
		Niagara,	6	
		Trenton,	5	
		Canadian,	4	
		Primordial,	3	
1. Archæan, or Eozoic.	1. Archæan.	Huronian,	2	
		Laurentian,	1	

As we have already stated, the gaps in the series are usually indicated by unconformity. Now, since unconformity always indicates movements of the crust, changes of the outlines of sea and land, changes of climate, and consequent changes in the fauna and flora, these gaps mark the times of great revolutions in the earth's history, and are therefore the natural boundaries of the eras, periods, etc. The whole rock-series,

therefore, is divided, by means of unconformity and the character of the fossils, into larger groups called *systems*, and these again into smaller groups called *series and formations.* The largest groups are founded upon universal, or almost universal, unconformity, and a consequent very great difference in character of organisms; the smaller groups are founded upon a less general unconformity and less difference in character of the organisms. Corresponding with the great divisions and subdivisions of the rock-system are the *eras*, *ages*, *periods*, and *epochs* of the history. The several terms expressing the divisions and subdivisions, both of the *rocks* and of the *history*, are unfortunately used in a loose manner. We will try to use them in the manner indicated. It will be observed that the divisions are founded upon (*a*) unconformity, and (*b*) change in fossils. These generally accompany each other, since they are produced by the same cause, viz., change of physical geography. In some localities, however, they may be in discordance. In this case, the change of fossils is considered the more important, and controls classification.

CHAPTER III.

UNSTRATIFIED OR IGNEOUS ROCKS.

Characteristics.—The unstratified are distinguished from the stratified rocks, *a*, by the absence of true stratification—i. e., lamination of sorted materials ; *b*, by absence of fossils ; *c*, by a more or less crystalline or else a glassy structure ; and, *d*, by their mode of occurrence explained below.

General Origin.—They have consolidated from a fused or semi-fused condition, and are, therefore, called *igneous rocks.* This origin is shown by their structure ; by their occurrence in dikes and tortuous veins ; by their effects on stratified rocks with which they come in contact ; and by their resemblance in many cases to modern lavas. The question of their probable mode of origin will be more specifically treated after the description of their kinds.

Mode of Occurrence.—Igneous rocks occur, *a*, underlying the strata, and forming the great mass of the earth's interior ; *b*, forming the axes and peaks of nearly all great mountain-ranges ; *c*, in vertical or nearly vertical sheets, filling great fissures in stratified or in other igneous rocks ; *d*, in extensive horizontal sheets overlying the stratified country rock, as if outpoured on the surface ; and, *e*, lying conformably between strata, as if forced in a melted condition between them, or else outpoured on the bed of the sea and afterward covered with sediment. All these positions are illustrated in Fig. 184. In all

these modes of occurrence the observed rock is connected with an underlying mass, of which it is but an extension.

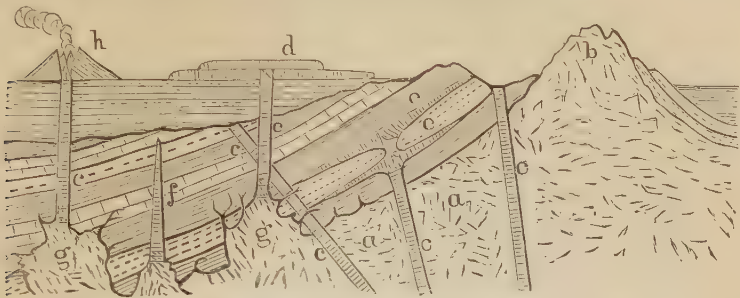


FIG. 184.—Diagram showing Mode of Occurrence of Igneous Rocks.

Extent on the Surface.—The appearance of these rocks on the surface is far less extensive than that of the stratified rocks. Certainly not more than one-tenth of the land-surface is composed of them. But, beneath, they are supposed to constitute the great mass of the earth.

Classification of Igneous Rocks.—Igneous rocks are best classified, not by means of their relative ages, but partly by their mineralogical character and partly by their mode of occurrence. By this method they most naturally fall into two primary groups—viz., the *Plutonic*, or massive, and the *volcanic*, or true eruptive rocks. The rocks of the first group occur in great masses ; those of the second group injected into fissures or outpoured on the surface. The former are *entirely* crystalline, and usually very *coarse-grained* (macro-crystalline) ; the latter are usually *finer grained* (micro-crystalline), or *imperfectly* crystalline (crypto-crystalline), or partly or even wholly *glassy*. The former seem to have solidified *in situ* (indigenous) ; the latter have been evidently *displaced* from their original position (exotic). The two groups, however, pass by insensible gradations into each other, so that the distinction is more or less artificial, and the same rock may sometimes be found in both groups.

I.—Plutonic or Massive Rocks.

General Appearance.—The rocks of this group are characterized by a coarse-grained, mottled, or speckled appearance, arising from the fact that they are composed of an aggregation of distinct crystals of different colors and of considerable size (macro-crystalline) ; and, what is much more important, the rock is usually *wholly made up of an aggregation of such crystals*, without any paste or ground-mass, either amorphous or glassy, between them.

The constituent minerals of this group are mainly quartz, feldspar, mica, and hornblende. In the speckled mass the opaque, white, or reddish or greenish crystals with glistening surface are feldspar, the trans-

parent bluish glassy spots are quartz, and the black specks are usually hornblende. The mica can be easily detected as glistening scales of various shades.

FIG. 185.—Graphic Granite: *A*, cross-section; *B*, longitudinal section.

Principal Kinds—Granite.—This rock, which may be regarded as the type of the group, consists of quartz, feldspar, and mica, or else of these, together with hornblende. Sometimes the mica and hornblende are wanting, and the quartz exists in the form of bent plates imbedded in feldspar, so that on cross-section they look like Hebrew or Arabic characters (Fig. 185, *A* and *B*). The rock is then called graphic granite, or *pegmatite.* Sometimes the feldspar is in large, well-formed crystals in a finer but still crystalline ground-mass; then it is called *porphyritic granite.* Sometimes all the crystals are small, and the mass is evenly granular; then it is called *eurite*, or granulite.

Syenite.—English and many American writers use this term to designate a granitic rock in which mica is replaced by hornblende; and, when both hornblende and mica are present, they use the term *syenitic granite.* But on the Continent of Europe the term syenite is applied to a rock consisting essentially of feldspar and hornblende, and when, in addition, quartz is present (English syenite), they call the rock *quartz-syenite.* The general aspect of the rock is similar to granite.

In the rocks thus far mentioned the feldspar is an *orthic*, or *potash-feldspar* (*orthoclase*)—i. e., is a double silicate of alumina and potash.

Diorite.—This is a dark, speckled, greenish-gray rock, consisting of a crystalline aggregate of *clinic*, or *soda-lime feldspar* (*plagioclase*), and *hornblende;* and, therefore, differs from syenite of German writers only in the form of the feldspar—viz., *plagioclase* instead of *orthoclase.* When quartz is present it is called quartz-diorite.

Diabase.—This is a dark, greenish crystalline rock, usually fine-grained, but sometimes granitoid, somewhat similar in appearance to diorite, but differing in the fact that *augite* replaces hornblende. It also often contains olivin. *Gabbro* is a granitoid variety of diabase.

We have selected these as good types of the groups; but they merge insensibly into each other, giving rise to many varieties, for

the description of which we must refer the reader to special treatises on lithology.

Diorite and diabase are so frequently intrusive and fine-grained that they are often treated in an intermediate or even in the second group; but they also often occur massive.

Two Sub-Groups—Acidic and Basic.—Quartz is pure silicic acid. Feldspar is a silicate of alumina and alkali, with excess of silica—i. e., an *acid silicate* of these bases. In orthoclase the alkali is potash; in plagioclase, soda and lime. Moreover, the former is more acid than the latter. Hornblende and augite are *basic* silicates of somewhat similar composition; but the latter the more basic of the two. Augite is essentially a silicate of magnesia and iron; while, in hornblende, alumina and lime replace a portion of the magnesia. Remembering, further, that quartz and feldspar are light-colored minerals, with specific gravity of about 2.6, while augite and hornblende are usually black minerals, with specific gravity of 3 to 3.5, it is plain that this group of rocks may be divided into two sub-groups, *acidic* and *basic*, often recognizable to the eye. In the one there is a predominance of quartz and feldspar, in the other of hornblende or augite. Also, in the one the feldspar is orthoclase, in the other plagioclase. The one is lighter colored, of less specific gravity, and more difficultly fusible; the other darker colored, heavier, and more easily fusible. Granite is the best type of the one, diorite, and especially diabase, of the other. Syenite is intermediate. The percentage of silica, both free and combined, in granite is 62 to 81, and the specific gravity 2.6 to 2.7. The silica percentage in diabase is 45 to 56, and the specific gravity 2.7 to 2.9 (Von Cotta).

Mode of Occurrence.—True Plutonics, especially of the *granitic type*, such as granite and syenite, occur: 1. In large masses, forming the axes of great mountain-ranges, such as the Sierra and Colorado ranges (Fig. 186, *A*); or, 2. In rounded masses, appearing in the midst of stratified rocks like islands in the midst of the sea (Fig. 186, *B*); or, 3. Sometimes in tortuous, irregularly branching veins, extending only a little way from the great masses into the overlying stratified rocks, as if forced by pressure of superincumbent weight into small cracks of the latter (Fig. 187, *A* and *B*). But rocks of more basic type, such as diorite and diabase, probably on account of greater fusibility, occur not only as Plutonics in massive form, but also as *intrusives* in dikes and intercalary beds, like true volcanics.

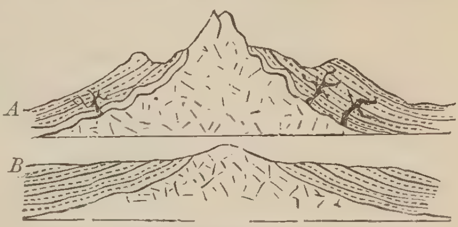


Fig. 186.—Diagram illustrating Mode of Occurrence of Granite.

The rocks of the Plutonic group are never found in connection with scoriæ, glass, ashes, or other evidences of rapid cooling in contact with air. They have never been erupted on the surface. They *were cooled, and have solidified under pressure at great depths. Hence, when we find them at the surface, they have been exposed by extensive*

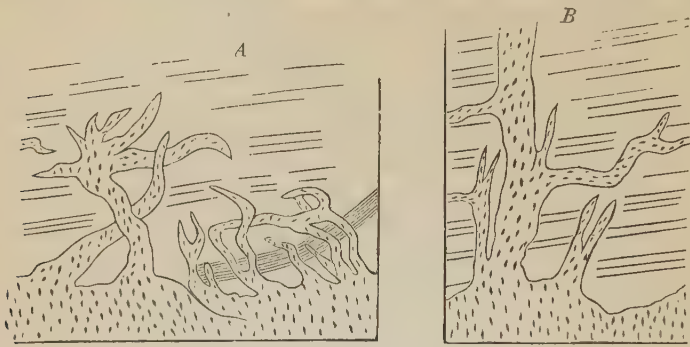


Fig. 187.—Granite Veins.

erosion. They are either fused masses, solidified without eruption (*a*), or they are the solidified reservoirs (*g*, Fig. 184) from which eruptions have come. In either case, they have themselves been cooled at great depths.

Intermediate Series.

Between the undoubted Plutonics, already described, and the undoubted volcanics, to be taken up hereafter, there is an intermediate series of rocks, which are sometimes placed in one group, sometimes in the other, and sometimes in a separate group coördinate with the other two and called *trappean* or *intrusive rocks.* They occur mostly in the older and middle rocks in the form of *dikes*, filling great fissures intersecting, or as intercalary beds between, the strata. If Plutonics are in great masses *beneath* the strata, and volcanics are outpoured masses *upon* the strata, these exist mostly as masses intruded *among* the strata. Again, if *Plutonics* are the great reservoirs and *volcanics* the outpoured liquid, the intrusives are the fillings of the conduits between. Erosion has subsequently carried away the overflowed portions, and exposed the conduits as dikes.

Kinds.—In the acidic groups, perhaps the most typical is *felsite.* This rock is a very compact, fine-grained aggregate of quartz and orthoclase, and therefore light-colored. Chemically it has the same composition as granite, and mineralogically it differs only in the fineness of texture and in the absence of mica. When the felsitic rock contains imbedded in the fine-grained mass large, well-formed crystals of feldspar, then it is called *porphyrite.* If quartz-crystals are also distinctly visible, then it is called *quartz-porphyry*, or *elvanite*, a

mottled rock often mistaken for granite. The word *porphyritic* is often applied to any rock in which distinct crystals are visible in a finer ground-mass. Thus, we have porphyritic granite, porphyritic diorite, etc.

Intrusive rocks of the basic sub-group are usually called *greenstones* or *traps.* This term, therefore, includes intrusive diorites, diabases, aphanites, etc. These differ from the massive rocks of the same composition only by being finer grained; but the same is true also of felsites as compared with granites. The difference is probably wholly due to rate of cooling. The same fused mass which, if cooled slowly, forms granite, if injected into fissures and cooled more rapidly, would form felsite or quartz-porphyrite. The difference between massive and intrusive diorites is doubtless due to the same cause.

II.—Volcanic or Eruptive Rocks.

Texture and Appearance.—The rocks of this group are usually micro-crystalline, or even crypto-crystalline, and therefore in appearance are either minutely speckled or evenly grayish, of various shades. But the most important characteristic is, that they are not wholly crystalline, but consist either of crystals imbedded in an amorphous or glassy paste, or else are wholly amorphous or glassy. This texture shows that, as compared with the rocks of the other groups, they have *cooled quickly*, for, on account of the extreme viscosity of fused silicates (glass), complete crystallization can take place only by very slow cooling.

Physical Conditions.—All the physical conditions already described (p. 84) as characteristic of recent lavas, viz., the *stony*, the *glassy*, the *scoriaceous*, and the *tufaceous* conditions, are found abundantly in the more typical representations of this group.

Mineral Composition and Sub-Groups.—The most striking differences between the rocks of this and the other groups are found in their texture and mode of occurrence. Mineralogically the rocks of this group consist essentially of some form of feldspar, with hornblende or augite. Free quartz and mica, though sometimes present, especially the former, are neither necessary nor common. These also, like those of the other group, may be divided into two sub-groups, *acidic* and *basic.* In the one there is a predominance of orthic feldspar (sanidin); in the other of either hornblende or augite and clinic feldspar (plagioclase). In true volcanics, as seen above, sanidin takes the place of orthoclase of the Plutonics. These, however, belong to the same group (orthoclase group), are equally acidic, and therefore have the same significance in lithology. The two sub-groups are, therefore, characterized by color, specific gravity, and fusibility, as already explained (p. 205), and, with some practice, can usually be distinguished in the field; though

in many cases microscopic or chemical examination is necessary. The silica percentage of the extreme acidic type (rhyolite) is 70 to 82, and specific gravity 2.3 to 2.6; of the extreme basic (basalt) the silica percentage is 40 to 56, and specific gravity 2.9 to 3.1. The following schedule gives the most common and characteristic kinds under the two sub-groups:

VOLCANIC ROCKS.		
	ACIDIC.	BASIC.
Stony condition.	Rhyolite. Liparite. Trachyte. Phonolite.	Basalt. Dolerite. Andesite. Propylite.
Glassy condition.	Light-colored scoriæ. Pumice. Obsidian.	Black scoriæ. Tachylite.

Principal Kinds.—In the acidic group the commonest and best type is *trachyte.* This is usually a light-colored rock, with a peculiar and very characteristic rough feel, due to microscopic vesicularity. It consists essentially of a ground-mass of orthic feldspar (sanidin) and augite, containing crystals of the former.

Rhyolite is similar in composition to trachyte, but contains a larger percentage of silica, and is very different in general appearance. It consists of a fluent, vitreous ground-mass or paste, usually containing crystals of sanidin, or even of quartz. When these crystals are conspicuous, so that the rock has a porphyritic appearance, it is called *liparite.* In some cases it may have even a granitoid appearance, and is then called *nevadite.* Such granitoid rhyolite may be easily distinguished from true granite by the presence of the paste.

Phonolite is a light-grayish crypto-crystalline feldspathic rock, breaking or jointing in very characteristic thin tile-like slabs, which ring under the hammer (hence the name). It consists mainly of orthic feldspar (sanidin and nephelin).

In the *basic sub-group* the most common and typical is *basalt.* This is a very dark, almost black, crypto-crystalline rock, breaking with a dull, conchoidal fracture, and consisting essentially of microscopic crystals of plagioclase, augite, and olivin, in a ground-mass of the same. Magnetite is also usually an abundant constituent. *Dolerite* has a somewhat similar composition, but lacks the olivin, and is more crystalline in structure, and therefore dark-grayish in appearance. *Andesite* is a dark-grayish rock, consisting essentially of plagioclase, with hornblende or augite. It is somewhat similar in color to dolerite,

but is crypto-crystalline, like basalt, and often roughish to the feel, like trachyte. It has, therefore, been sometimes called trachy-dolerite.

All the rocks of both these sub-groups, but especially the more typical, have their scoriaceous and glassy varieties. These are the pumices and light-colored scoriæ and obsidians on the one hand, and the black scoriæ and tachylite on the other.

The following table is a condensed statement of the composition of the principal kinds in both primary groups, including also intrusives. The sign × × indicates crystals :

IGNEOUS ROCKS.

		ACIDIC.			BASIC.	
II. VOLCANIC ROCKS	Occurring in overflows.	*Rhyolite.* Vitreous base. + × × Quartz, Orthoclase (sanidin).	*Trachyte.* Base. + × × Orthoclase (sanidin).	*Phonolite.* Base. + × × Sanidin, Nephelin.	*Andesite.* Base. + × × Plagioclase, Augite, or Hornblende.	*Basalt.* Base. + × × Plagioclase, Augite, Olivin.
I. PLUTONIC ROCKS.	Occurring in intrusions.	*Quartz-porphyry.* Micro × × ground-mass. + × × Orthoclase, Quartz.		*Felsite.* Micro × × Orthoclase, Quartz.	*Diorite.* See below.	*Diabase.* See below.
	Occurring massive.	*Granite.* × × Quartz, Orthoclase, Mica.		*Syenite.* × × Orthoclase, Hornblende.	*Diorite.* × × Plagioclase, Hornblende.	*Diabase.* × × Plagioclase, Augite.

Modes of Eruption.—There have been in geological times two general modes of eruption. In the one the lavas have come up through *great fissures* formed by crust-movements and spread out as extensive *sheets ;* in the other they have come up through *chimneys* and run off as *streams.* The one may be called *fissure-eruption*, the other *crater-eruption* or volcanoes proper. The one gives rise to extensive *lava-fields*, the other to *lava-cones.* The force of eruption in the one case is probably either the same as that which makes mountains—i. e., the lava is squeezed out by interior contraction of the earth, or else, in some cases it may be hydrostatic—i. e., a *welling out* of a lighter liquid by the sinking of a heavier crust within it ; the force, in the other case, is evidently the pressure of elastic gases, especially steam, as already explained (page 90). We owe this distinction mainly to Richthofen, but it is now universally adopted in this country and quite generally in Europe. According to Richthofen, *primary* eruptions come always through great fissures and only at great intervals of time ; afterward, surface-waters percolating through these fissure-erupted masses, still

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liquid within, give rise to *secondary* eruptions through craters. We have no examples of fissure-eruptions taking place at the present time, and therefore, in treating of igneous agencies in Part I., we spoke only of crater-eruptions. But it is impossible to explain the mode of occurrence of eruptions in the older rocks unless we admit eruptions in early geological times of a different kind from those occurring now in volcanoes.

Modes of Occurrence.—True eruptive rocks occur: 1. As extensive vertical sheets filling *great* fissures which by subsequent erosion outcrop as great *dikes*, or else filling smaller radiating volcanic fissures as radiating volcanic dikes; 2. As sheets between the strata (intercalary beds) as if forced between the separated strata, or else outpoured on the bed of sea or lake, and again covered with sediments; 3. Outpoured on the land-surface as sheets or streams; and, 4. In the form of great dome-like masses on the surface or between the strata.

Dikes.—The fillings of great fissures outcropping on land-surfaces are called *dikes*. They are very abundant in all the older stratified rocks, especially in mountain-regions. They vary in thickness from a few inches to fifty or one hundred feet; they may be traced over the country sometimes for many miles, even fifty or one hundred, and extend downward to great but unknown depths. Such dikes, outcropping over the face of the country, may be the exposed roots of ancient overflows which have been removed by subsequent erosion; or they may be fillings of fissures which never reached the surface (Fig. 184, *j*). In either case they are the evidence of extensive erosion. Sometimes the outcropping dike has resisted erosion more than the enclosing country rock, and the dike is left standing like a low, ruined wall running over the face of the country (Fig. 188, *a*); at other times the country rock has resisted more than the dike, and the place of the dike is marked by a slight depression, like a shallow ditch, or moat (Fig. 188, *b*).

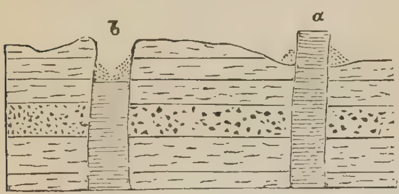


FIG. 188.—Dikes.

Effect of Dikes on the Intersected Strata.—The strata forming the bounding walls of a dike, or with which igneous rocks come in contact in any way, are almost always greatly changed by the intense heat of the fused matter. Limestones and chalk are changed into crystalline marble; clay is baked into porcelain-jasper, or even changed into schists; impure sandstones are changed into a speckled rock resembling gneiss; seams of bituminous coal are changed into anthracite, or sometimes into coke. In all cases the original stratification and the contained fossils are more or less completely destroyed. These

effects extend sometimes only a few feet, sometimes many yards, from the dike.

Lava-Sheets.—Dikes outcropping on the face of the country as already described, are doubtless in many cases the exposed roots of ancient overflows which have been removed by subsequent erosion, leaving only the *intruded* portion. But in more recent eruptions the overflow or *erupted* portions still remain. The fused matter has evidently come up through fissures and spread out as sheets, and often sheet after sheet has been successively outpoured, forming layer upon layer (Fig. 189), until the whole surface of the country is deeply buried beneath the flood. The extent and thickness of the lava-fields thus formed are almost incredible. The great lava-flood of the Northwest covers Northern California, Northwestern Nevada, the greater part of Oregon, Washington Territory, and Idaho, and extends far into British Columbia and Montana. Its extent is not less than 150,000 square miles, and its extreme thickness where cut through by the Columbia River is 3,000 to 4,000 feet. In another place seventy miles distant, the Deschutes River cuts into the same lava-field, making a cañon 140 miles long and 1,000 to 2,500 feet deep, and has not yet reached bottom. At least thirty successive layers may be counted, one above the other, on the sides of this cañon. About a dozen volcanoes overdot this great surface. It is simply inconceivable that all this material came from these volcanoes. It evidently came up through great fissures in the Cascade, Blue Mountains, and Coast Range, and poured out on the surface, flooding the whole intervening country.[1] The Deccan lava-field, described by the Indian geologists,[2] is 200,000 square miles in extent, 2,000 to 6,000 feet thick, and entirely without detectable volcanic cones from which the lava could have come. These extensive fields are mostly of basalt. In Utah and Colorado, according to King and Endlich,[3] rhyolitic and trachytic lavas reach a thickness of 7,000 feet. As a general rule, outpourings of basalt reach the greatest extent, but each sheet is thin, as if the basalt had been *superfused;* while acidic lavas like trachyte and rhyolite are outpoured in very

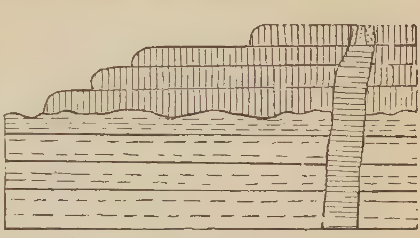


Fig. 189.—Lava-Sheets.

[1] *American Journal of Science*, vol. vii., pp. 167, 259.

[2] *American Journal of Science*, vol. xix., p. 148, 1880. "Manual of Indian Geology," p. 300, *et seq.*

[3] King, "Geology of the Fortieth Parallel," vol. i., p. 632. Endlich, Hayden's "Report" for 1876, p. 112.

thick, sometimes dome-like masses, as if they had been only *semi-fused.*

In basaltic lava-fields a remarkable step-like or terrace-like appearance is observable. The country seems to rise in successive tables or benches. From this has arisen the term *trap*, from the Swedish word *trappa*, a stair. This configuration is due to the abrupt terminations of the successive flows (Fig. 189).

Intercalary Beds and Laccolites.—Holmes, in Hayden's "Report" for 1875,[1] describes Mount Hesperus, Colorado, as wholly composed of stratified rocks (cretaceous), with intercalated beds of eruptives, as if the lava had forced itself between the strata. Such intercalary sheets, which have been often observed by others, probably pass by insensible gradations into *laccolites*—a new form of occurrence to which attention was first drawn by Holmes, but which has been elaborately described by Gilbert[2] as characteristic of the Henry Mountains, and other groups in the Plateau region. In this case the liquid matter seems to have come up through fissures as usual, but, instead of breaking through to the surface, has lifted the upper strata and accumulated beneath in great dome-like masses which, in fact, constitute the bulk of the mountains (Fig. 189b). The strata-covered dome thus formed is afterward eroded, and the igneous core or laccolite is exposed.

Fig. 189b.—Laccolite (after Gilbert).

According to Gilbert, whether lava accumulates between the strata or outpours on the surface is merely a question of relative specific gravity. If the lava is lighter than the strata, then the latter will sink and the lava be outpoured. If, on the other hand, the surface strata be lighter than the lava, then the lava floats it up and accumulates beneath. It seems more probable, however, that it is rather a question of *liquidity* than of specific gravity. If the liquidity is perfect as in basalts, then it comes to the surface and outpours, and may extend to very great distances; but, if, on the contrary, the lava is only a stiffly viscous, semi-fused mass, like trachyte and rhyolite, it may lift up the strata on its back in a dome.

Age—how determined.—When two dikes intersect each other, then, of course, the intersecting must be younger than the intersected dike. In this manner the *relative* age of dikes intersecting the same region

[1] Hayden's "Report" for 1875, p. 271.

[2] Gilbert, "Geology of the Henry Mountains."

may often be determined. The *absolute* age of igneous rocks can only be determined by means of the strata with which they are associated. If a dike is found intersecting strata of known age (*c*, Fig. 184), the dike must be younger than the strata. If a dike (*c'*), intersecting strata and outcropping on the surface, is found overlaid by other strata through which it does not break, then the igneous injection is younger than the former and older than the latter. The series of events indicated is briefly as follows: first, the older series of sediments has been formed; then fissures formed and filled by igneous injection; then erosion has carried away the upper portion of the strata and its included dike, so that the dike outcrops along the eroded surface; and, lastly, the whole has been submerged and again covered with sediment.

In the case of intercalary beds of igneous rocks, if the strata above and below are both metamorphosed by heat, then the fused matter has been forced between and is younger than the strata; if, however, the underlying stratum is changed but the overlying is not, then the igneous matter has been outpoured on the sea-bed and covered with sediment, and is, therefore, of the same age as the strata. The same principles determine the age of *sheets* and *streams*. If sheets are successively outpoured, one atop the other, then, of course, the order of superposition determines their relative age. So, also, if two streams run across each other, the overlying is the younger. In this way Richthofen and others have determined the order of succession of different kinds of tertiary eruptives. *Absolute* age, or the geological time of eruption, can only be determined by the age of the associated strata.

Of Certain Structures found in many Eruptive Rocks.

Columnar Structure.—Many kinds of eruptive rock exhibit sometimes a remarkable columnar structure. This is most conspicuous in basalt, probably because this rock has been superfused, and is therefore sometimes called basaltic structure. Sheets and dikes of this rock are often found composed wholly of regular prismatic jointed columns,

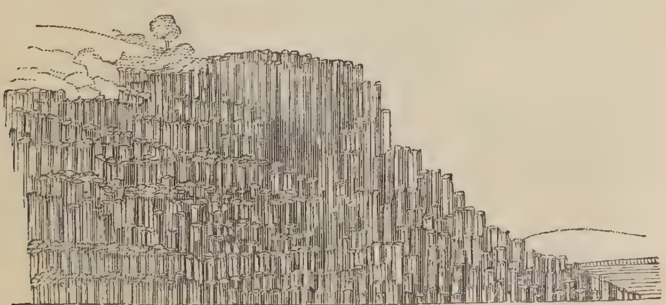


FIG. 190.—Columnar Basalt, New South Wales (Dana).

closely fitting together, varying in size from a few inches to a foot or more, and in length from several feet to fifty or one hundred feet. When these columns have been well exposed on cliffs by the action of waves, or on river-banks by the erosive action of currents, or even by atmospheric disintegration, they produce a very striking scenic effect (Figs. 190, 191.) In Europe the Giant's Causeway, on the coast of Ireland, and Fingal's Cave, in the island of Staffa on the west coast of Scotland, are conspicuous examples. In the United States we have

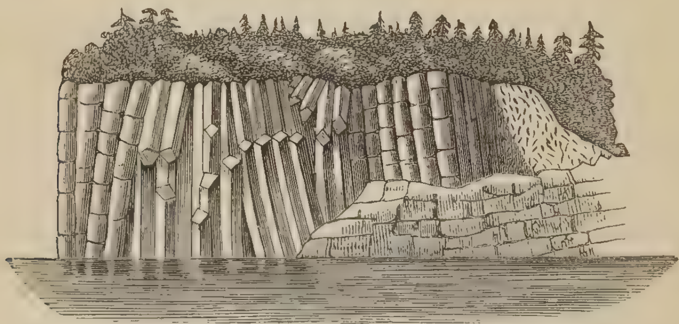


FIG. 191.—Basaltic Columns on Sedimentary Rock, Lake Superior (after Owen).

examples in Mount Holyoke, on the Connecticut River; in the Palisades of the Hudson River; in the traps on the shores of Lake Superior; and especially in splendid cliffs of the Columbia and Deschutes Rivers, in Oregon.

Direction of the Columns.—The direction of the columns is usually at right angles to the cooling surface. In horizontal sheets, therefore,

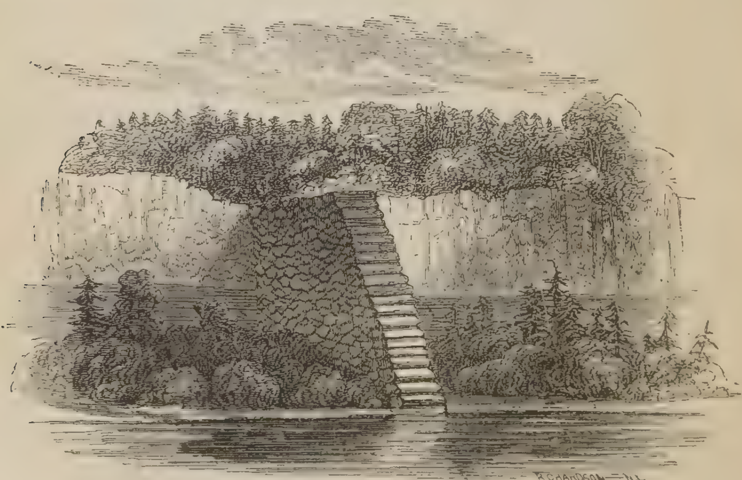


FIG. 192.—Columnar Dike, Lake Superior (after Owen).

the columns are vertical, but in dikes they are horizontal (Fig. 192). A dike left standing above the general surface of country sometimes presents the appearance of a long pile of cord-wood. In some cases the columns are curved and twisted in a manner not easy to explain; sometimes, instead of columnar, a *ball*-structure is observed.

Cause of Columnar Structure.—There is little doubt that this structure is produced by contraction in the act of cooling. Many substances break in a prismatic way in contracting. Masses of wet starch, or very fine mud exposed to the sun, crack in this way. In basalt the structure is more regular than in any other known substance. The subject of the cause of jointed columnar structure has been very ably discussed by Mr. Mallet.[1]

Volcanic Conglomerate and Breccia.—If a stream of fused rock, whether from a crater or a fissure, run down a stream-bed, it gathers up the *pebbles* in its course, and after solidification forms a conglomerate which differs from a true conglomerate (p. 171) in the fact that the uniting paste is igneous instead of sedimentary. In a similar manner volcanic breccias are formed by the flowing of a lava-stream over a surface covered with *rubble.*

The disintegration of volcanic rocks, and their transportation and deposit, will of course give rise to *aqueous* conglomerates and breccias composed of volcanic materials, which often are difficult to distinguish from true volcanic conglomerates and breccias. These aqueous conglomerates and breccias of volcanic material pass by insensible gradations into tufas, which, as already explained (page 84), consist of fine volcanic material cemented into an earth-mass and often sorted by water.

Amygdaloid.—Still another structure, very common in lavas and traps, is the amygdaloidal. The rock called amygdaloid (Fig. 193) greatly resembles volcanic conglomerate, being apparently composed of almond-shaped pebbles in an igneous paste, but is formed in a wholly different way. Outpoured traps, and especially lava-streams, are very often vesicular, i. e., filled with vapor-blebs, usually of a flattened, ellipsoidal form. In the course of time these cavities are filled with silica, carbonate of lime, or some other material, by infiltrated water holding these matters in solution. Sometimes the filling has taken

Fig. 193.—Amygdaloid.

[1] *Philosophical Magazine*, August and September, 1875.

place very slowly by successive additions of different-colored material. Thus are formed the beautiful agate pebbles, or more properly *amygdules,* so common in trap. The most common filling is silica, because water percolating through igneous rocks is always alkaline, and holds silica in solution.

Some Important General Questions connected with Igneous Rocks.

1. *Origin of Igneous Rocks.*

There are many reasons for thinking that igneous rocks are not erupted portions of an original fused magma, but are usually the result of *refusion* of *stratified rocks.* This question has been already touched in treating of volcanoes (page 92), but we are now in condition to take it up more fully.

If the earth cooled from a primal incandescent, fused condition, it is evident that there would be substantial homogeneity in any given layer, at least in any given locality. Erupted matters, therefore, although they might indeed slowly change in composition in the course of geological ages, as deeper and deeper layers were successively reached by the gradual thickening of the earth's crust, yet, in the *same locality*, and erupted about the *same time*, they ought to have the same composition. But we find, on the contrary, lavas of the greatest differences ; e. g., rhyolite and basalt, erupted in the same region, and nearly at the same time. They cannot, therefore, be portions of the same original magma.

Now, in the primal solidification of the earth from fusion, the first crust was doubtless a homogeneous igneous rock, somewhat similar in composition to diorite or syenite. The effect of aqueous agencies on this original homogeneous material, by disintegration, transportation, sorting, and deposit, throughout all geological times, has been to produce *extreme differentiation of stratified rocks*, belonging to the same time and in the same region. Hence, if eruptives are produced by refusion of these, we would expect to find great diversity among them.

But, on the other hand, the *extreme* diversity which we find among stratified rocks, viz., pure sandstones (acid), on the one hand, and pure limestones (base) on the other, *is not found among igneous rocks.* But this, which seems at first an objection, is found, on examination, a confirmation of our conclusion ; *for these extremes are infusible.* Thus the diversity of composition of igneous rocks is completely explained by supposing them formed by refusion of stratified rocks *within the limits of ready fusibility.*[1]

[1] Captain Dutton, "High Plateaus of Utah," p. 120.

2. *Other Modes of Classification.*

There is no subject connected with geology which is in a state of greater confusion than the classification and nomenclature of igneous rocks. It seems proper, therefore, to mention some of the different views entertained.

Many geologists think that igneous rocks may be thrown into three groups, characteristic of different periods of the earth's history, and which, therefore, are now found associated with the stratified rocks of different ages. These are: 1. The granitic group, including granites and syenites, associated with archæan and palæozoic rocks; 2. The trappean group, including diorites, porphyry, dolerite, etc., associated with the later palæozoic and the mesozoic rocks; and, 3. The volcanic rocks, including basalts, trachytes, etc., associated with the tertiary rocks. They think, therefore, that the earliest eruptions were granitic, then trappean, and lastly volcanic. Furthermore, they think that the first have come up mostly in great, dome-like masses; the second, mostly intrusive, in dikes and fissures; and the third through craters forming volcanoes.

Again, many think that erupted matters, of different times, have become progressively *more basic*. They think that, although each group may be divided into a more acidic and a more basic sub-group, yet, as a whole, the granitic group is the most acidic and the volcanic the most basic, the trappean being intermediate, as shown in the accompanying diagram:

ACID.	
Acidic.	Basic.
Granitic.	
Granite.	Syenite.
Trappean.	
Porphyry.	Diorite.
Volcanic.	
Trachyte.	Basalt.
BASIC.	

Again, these two views, which are usually held by the same persons, are by them connected with a third view, in regard to the original constitution of the earth's crust. On first cooling, the outer layer is supposed to have been highly oxidized, highly siliceous, and therefore comparatively light—in other words, *granitic;* beneath this was a less oxidized, less acid layer, and so on progressively, the deeper layers becoming heavier and heavier, and more and more basic. The first eruptions were from the outer layer, and therefore granitic. Afterward, as the crust grew thicker and thicker, the eruptions were from deeper and deeper layers, and therefore denser and denser, and more and more basic.

But, in answer to these views, it may be said that, as to *age*, there can be no doubt that granite, though most commonly associated with the older rocks, is found in strata of all ages up to the middle Tertiary,

and fissure eruptions have occurred in all ages up to the latest Tertiary. The granite of Mont Blanc was pushed up at the end of the Eocene (Lyell), and the great fissure-eruptions of the Northwest took place during the Pliocene.[1] Also, as to *composition*, trachyte and liparite have much the same chemical composition as granite, except that more of the silica is in *combination* and less of it *free* in the former than in the latter. Some early diorites and gabbros have much the same chemical (if not mineralogical) composition as basalt.

Again, others, with much reason, think that all the differences between the three groups in mineralogical character and crystalline structure are due wholly to the different depths at which and the slowness with which solidification took place. They think, therefore, that if trachyte (Fig. 184, *h*) could be traced downward deep enough it would pass into porphyry (*c*), and finally into granite (*g*), and similarly basalt would pass into dolerite and diorite, and finally into olivin-diabase.[2] On this view, what *we* cannot do, has been done for us by *erosion ;* and granite is most commonly associated with older rocks only because these have been most eroded, and therefore their deeper parts, or even the fountain-reservoirs from which eruptions have come, have been exposed. Similarly, a less extreme erosion of the mesozoic rocks has exposed the porphyritic and dioritic dikes through which eruptions came up ; while, of the modern lavas, only the upper or overflowed parts are exposed. This view explains completely all the phenomena of igneous rocks, and the gradations between them, in chemical and mineralogical composition and in crystalline structure, and is therefore very probably true. We have substantially assumed it in the preceding descriptions.

The confusion in the classification and nomenclature of igneous rocks is still further increased by the undoubted fact that many of the kinds of rocks mentioned above as igneous are found also among metamorphic rocks which have never been erupted at all. This subject is further treated under the head of Metamorphism (p. 223).

3. *Richthofen's Classification of Tertiary Eruptives.*

By far the most successful attempt to classify by age, or to correlate the kinds of igneous rocks with their ages, is found in Richthofen's classification of Tertiary eruptives. This classification has been so generally adopted by the United States geologists that some account of it seems necessary. According to Richthofen, there is a regular and invariable order of succession among the eruptive rocks of Tertiary times ; the order being—1. Propylite.[3] 2. Andesite. 3.

[1] *American Journal of Science*, vol. vii., p. 167, 1874.

[2] This gradual change has very recently been distinctly observed in Southeastern Europe by Judd (*Geological Magazine*, 1876, vol. xxxii., p. 292), and also in Colorado by Peale (Hayden's "Report" for 1873, p. 261).

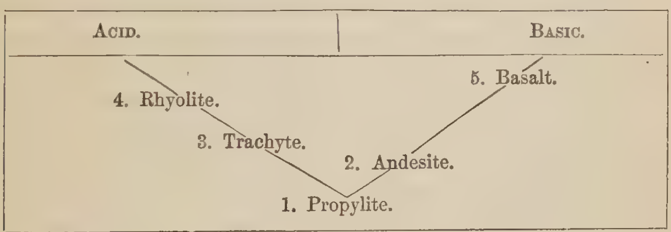
[3] Propylite is regarded by many as a variety of andesite.

Trachyte. 4. Rhyolite. 5. Basalt. This order, however, applies only to *primary or fissure eruptions;* for, since primary erupted masses may become the seats of subsequent secondary or crater eruptions, it is evident that secondary eruptions of a lower group may be synchronous with primary eruptions of a higher group.[1]

Now, the order given above is the order neither of composition nor of density nor of fusibility. It would seem, therefore, *a priori*, highly improbable. Yet the order was founded by Richthofen on wide observation both in Europe and in this country, and it has been confirmed for eruptives of the Western portion of the continent by King, Zirkel, Dutton, and Endlich. Any explanation, therefore, however hypothetical, of so singular a fact, deserves attention.

Dutton's Theory of the Cause of Richthofen's Order.

Captain Dutton has brought forward an ingenious explanation, which may be briefly summarized thus :[2] 1. He shows that the above order is the order of gradual *differentiation* from a generalized type. The earliest, viz., propylite, is such a generalized type. In andesite and trachyte, the next in order, the basic and acidic are already separated, but not greatly ; in rhyolite and basalt the divergence becomes extreme. The whole series may therefore be written thus :



2. He assumes that Tertiary eruptives are the result of refusion of sedimentary rocks by heat, the source of which is unknown, but which steadily increases so long as the cause operates in any given locality. 3. He assumes that fissure-eruptions are the result of a sinking of a heavier crust into a lighter liquid, and a welling out of that liquid ; and, therefore, that the act of eruption is determined only by the relative densities of crust and underlying liquid which is ever growing lighter by increasing heat. The order of eruption of different parts of the liquid, produced by fusion of different kinds of strata, is merely the order of their densities taken in connection with the order of their fusibilities.

[1] Richthofen's "Natural History of Volcanic Rocks," "Memoirs of California Academy of Science," vol. i., Part II.

[2] Dutton, "Geology of High Plateaus," p. 131.

Application.—Suppose a layer of stratified rock composed of various kinds of materials undergoing fusion successively in the order of fusibility, by very gradually increasing heat, and thus producing different kinds of fused igneous rocks. Basalt will melt first, but is too heavy to erupt. Rhyolite is lightest, but most infusible, and therefore not yet melted. Therefore, an intermediate variety will first reach the double condition of fusion and lightness necessary to produce eruption. Such an intermediate variety is propylite, and the rest would follow in the order given. Rhyolite will be late, because so difficult of fusion. Basalt will be last, because, though easily fused, it is so heavy that superfusion is necessary to produce sufficient lightness. This would account for the fact, otherwise inexplicable, that basalt always shows signs of superfusion, while rhyolite and trachyte signs of semi-fusion.

It is hardly necessary to say that this view, although deserving of much attention, must be regarded as tentative. All that is as yet universally accepted in regard to the order of Tertiary eruptives is that the trachytes (including in this term with the trachytes proper also the andesites and the rhyolites) precede the basalts. The reason of this may possibly be found in the fact that acidic rocks, although more infusible than the basics *to dry heat*, yet *yield very easily to hydrothermal fusion* by the formation of hydrous silicates. Now, it is in this condition of imperfect hydrothermal fusion that the trachytes and rhyolites were erupted, while the basalts have been in a state of complete igneous fusion. If we suppose strata of different kinds to be subjected to steadily increasing heat in the presence of a small percentage of water, it is easily conceivable that the acidic rocks would first yield by hydrothermal fusion, and only afterward the basic rocks by true igneous fusion.

Judd, in his recent work on "Volcanoes," admits that an intermediate type like andesite (propylite is usually regarded as a variety) is first erupted, then an acid type like trachyte and rhyolite, and last basalt. He accounts for this by supposing a homogeneous fused mass (such as would be formed by fusion of many different kinds of strata), to be first erupted as soon as formed. This would make an intermediate type. The remainder of the fused mass after long standing would separate into a lighter acid portion above and a heavier basic portion below. These would, therefore, be successively erupted as rhyolite and basalt.

CHAPTER IV.

METAMORPHIC ROCKS.

There is a third class of rocks, intermediate in character between the ordinary sedimentary and the igneous rocks, and therefore put off until these had been described. The rocks of this class are stratified, like the sedimentary, but crystalline, and usually non-fossiliferous, like the igneous rocks. They graduate insensibly on the one hand into the true unchanged sediment, and on the other into true igneous rocks.

Origin.—Their origin is evidently sedimentary, like other stratified rocks, but they have been subsequently subjected to heat and other agents which have changed their structure, sometimes entirely destroying their fossils and even their lamination structure, and inducing instead a crystalline structure. The evidence of their sedimentary origin is found in their gradation into unchanged fossiliferous strata; the evidence of their subsequent change by heat, in their gradation into true igneous rocks. For this reason they are called *metamorphic* rocks.

Position.—All the lowest and oldest rocks are metamorphic. The converse, however, viz., that metamorphic rocks are always among the oldest, is by no means true. Metamorphism is not, therefore, a test of age. Metamorphic rocks are found of all ages up to the Tertiary. The Coast Range of California is much of it metamorphic, although the strata belong to the Tertiary and Cretaceous periods. Metamorphism seems to be *universal* in the Laurentian, is *general* in the Palæozoic, *frequent* in the Mesozoic, *exceptional* in the Tertiary, and entirely *wanting* in recent sediments. It is therefore less and less common as we pass up the series of rocks. The *date* of metamorphism is also different from that of the origin of the strata. Metamorphism has taken place in all geological periods, and is doubtless now progressing in deeply-buried strata.

Metamorphism is also generally associated with foldings, tiltings, intersecting dikes, and other evidences of igneous agency, and is therefore chiefly found in mountainous regions. It is also usually found only in very *thick strata.*

Extent on the Earth-Surface.—These rocks exist, outcropping on the surface, over wide regions. Nearly the whole of Canada and Labrador, a large strip on the eastern slope of the Appalachians, and a large portion of the mountainous regions of the western border of this continent, are composed of them. Beneath the surface they probably underlie all other stratified rocks. Their thickness is also often immense.

The Laurentian series of Canada is probably 40,000 feet thick, and metamorphic throughout.

Principal Kinds.—The principal kinds of metamorphic rocks are: *Gneiss*, *mica-schist*, *chlorite-schist*, *talcose-schist*, *hornblende-schist*, *clay-slate*, *quartzite*, *marble*, and *serpentine.*

Gneiss, the most universal and characteristic of these rocks, has the general appearance and mineral composition of granite, except that it is more or less distinctly stratified. Often, however, the stratification can only be observed in large masses. *Gneiss* runs by insensible gradations, on the one hand, into granite, and on the other, through the more perfectly stratified schists, into sandy clays or clayey sands.

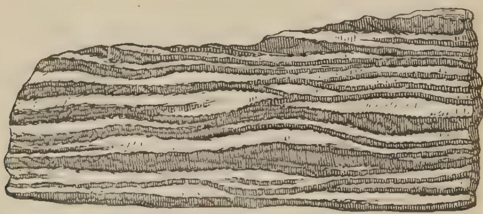


FIG. 194.—Gneiss.

The *schists* are usually grayish fissile rocks, made up largely of scales of *mica*, or *chlorite*, or *talc.* Hornblende-schist is similarly made up of scales of hornblende, and is therefore a very dark rock. The fissile structure of schists is due to the presence of these scales, and is therefore wholly different from that of *slates.* It is called *foliation-structure.*

Serpentine is a compact, greenish magnesian rock. The other varieties need no description. Hornblende-schists run by insensible gradations into clay-slates on the one hand, and into diorites and syenites on the other.

All these kinds may be regarded as changed sands, limestones, and clays, the infinite varieties being the result of the difference in the original sediments and the degrees of metamorphism. Sands and limestones are often found very pure; such when metamorphosed produce quartzite and marble. Clays, on the contrary, are almost always impure, containing sand, lime, iron, magnesia, etc. Such impure clays, if sand is in excess, produce by metamorphosis gneiss, mica-schist, and the like; but if lime and iron are in considerable quantities they produce hornblende-schist or clay-slate; if magnesia, talcose-schist. The origin of serpentine is not well understood; but it is evidently in most cases a changed magnesian clay. All gradations between such clays and serpentine may be found in the Tertiary and Cretaceous strata of the Coast Range of California.

Theory of Metamorphism.

There are few subjects more obscure than the cause of metamorphism, and the conditions under which it occurs. Some important light has been thrown on it, however, recently. For the sake of clearness, it will be better to divide metamorphism into two kinds, somewhat different in their causes, viz., *local* and *general.*

Local Metamorphism is that produced by direct contact with evident sources of intense heat, as when dikes break through stratified rocks. As already seen (p. 210), under these circumstances, impure sandstones are changed into schists, or into gneiss; clays, into slates, or into porcelain jasper; limestones, into marbles; and bituminous coal, into coke, or into anthracite. In these cases it is evident that the cause of the change is the intense heat of the incandescent, fused contents of the dike at the moment of filling. In such cases of local metamorphism, the effects usually extend but a few yards from the wall of the dike.

General Metamorphism.—But in many cases we cannot trace the change to any evident source of intense heat. Rocks, thousands of feet in thickness, and covering hundreds of thousands of square miles, are universally changed. The principal agents of this general metamorphism seem to be *heat*, *water*, *alkali*, *pressure.*

That *heat* is a necessary agent is sufficiently evident from the general similarity of the results to *local* metamorphism. But that the heat was not intense, and therefore not sufficient of itself to produce the effects, is also quite certain. For (*a.*) metamorphic rocks are often found interstratified with unchanged rocks. Intense heat would have affected them all alike, or nearly alike. (*b.*) Many minerals are found in metamorphic rocks which will not stand intense heat. As an example, carbon has been found in contact with magnetic iron-ore, although it is known that this contact cannot exist, even at the temperature of red-heat, without reduction of the iron-ore. (*c.*) The effect of simple dry heat, as shown in cases of local metamorphism, does not extend many yards. (*d.*) *Water-cavities* are found abundantly in metamorphic rocks. This will be more fully explained farther on.

Water.—Heat combined with water seems to be the true agent. Recent experiments of Daubrée, Senarmont, and others, prove that water at 400° C. (= 752° Fahr.) reduces to a *pasty condition* nearly all ordinary rocks; moreover, that at this temperature crystals of quartz, feldspar, mica, augite, etc., are formed. Such a pasty or aqueo-fused mass slowly cooled would form a crystalline rock containing crystals of quartz, feldspar, mica, etc.; in other words, would be metamorphic. The quantity of water necessary for these effects is shown by experiment to be very small—only five to ten per cent. In other words, *the included water of sediments is amply sufficient.*

Alkali.—Alkaline carbonates, or alkaline silicates, so common in natural waters, greatly promote the process, causing the aqueo-igneous pastiness or aqueo-igneous fusion to take place at a much *lower temperature.*

Pressure.—Simple pressure is not itself a direct agent, but the necessary condition for the action of the others, since it is impossible to have high temperature in the presence of water without corresponding pressure.

It is evident, therefore, that while metamorphism by dry heat would require a temperature of 2,000° to 3,000° Fahr., in the presence of water the same result is produced at 572° to 752° Fahr. (300° or 400° C.); or in the presence of alkali, even in small amount, probably at 300° or 400° Fahr.

Application.—All these agents are found associated in deeply-buried sediments. Series of outcropping strata are often found 20,000 or even 40,000 feet thick. The lower strata of such a series, by the regular increase of interior heat alone, must have been, before uptilting, at a temperature of between 700° and 800° Fahr., a temperature sufficient, with their included water, to produce complete aqueo-igneous pastiness, and therefore, by cooling and crystallization, complete metamorphism.

Suppose, then, *a b b*, Fig. 195, represent the contour of land and sea-bottom at the beginning of any period, and the dotted line *i i* the

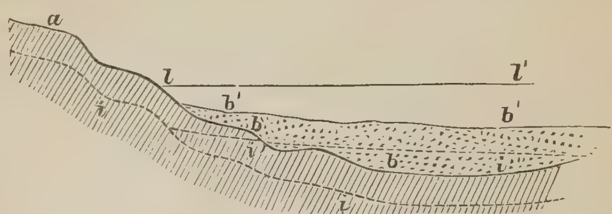


FIG. 195.—Diagram illustrating the Invasion of Sediments by the Interior Heat.

isogeotherm of 800°. If, now, sediments 40,000 to 50,000 feet thick be deposited so that the sea-bottom is raised to *b′ b′*, then the isotherm of 800° will rise to *i′ i′* and invade the lower portions of the sediments with their included water. Such sediments would be completely changed in their lower portions, and to a less extent higher up. It is probable that even 300° to 400° Fahr. is sufficient to produce a considerable degree of change; or even 200°, if alkali be present.

Crushing.—Although simple gravitative pressure is only a condition, and not a cause, of heat, *horizontal pressure with crushing* of the crust, by the conversion of mechanical energy into heat, becomes, as Mallet has shown,[1] an active source of this agent. Now, in all cases

[1] "Philosophical Transactions," 1873, p. 147.

of metamorphism we find ample evidences of such horizontal crushing in the associated foldings and cleavage of the strata.

Explanation of Associated Phenomena. — This theory readily explains—1. Why metamorphism is always associated with great thickness of strata; 2. Why the oldest rocks are most commonly metamorphic, since these have usually had the newer rocks piled upon them, and have been subsequently exposed by erosion. The newer rocks are sometimes also metamorphic, but in these cases they are *very thick.* 3. It also explains the interstratification of metamorphic with unchanged rocks; since some rocks are more easily affected by heated water than others, and the composition of the included water may be also different, some containing alkali and some not. 4. It also explains its association with foldings of strata and with mountain-chains, as will be more fully explained hereafter.

If metamorphism is only produced in deeply-buried sediments, then the exposure of such rocks on the surface can only result from extensive erosion.

Origin of Granite.

There is much reason to believe that most granites are not the result of simple dry fusion, as is usually supposed; but, on the contrary, only *the last term of metamorphism of highly-siliceous sediments.* According to this view, incipient pastiness by heat and water makes gneiss; complete pastiness, completely destroying stratification, makes granite. The principal arguments for this view may be briefly stated as follows:[1]

1. In many localities in mountain-regions, and nowhere better than in the Sierras of California, every stage of gradation may be observed between clayey sandstones and gneiss, and between gneiss and granite. So perfect is this gradation, that it is impossible to draw sharply the distinction. Even geologists who believe that granite is *the primitive* rock have been compelled to admit that there is also a metamorphic granite, scarcely distinguishable from primitive granite.

2. Not only gneiss, but even granite, is sometimes interstratified with undoubted sedimentary rocks.[2]

3. Chemists recognize two kinds of silica, viz., an amorphous variety of specific gravity 2.2, and a crystallized variety, specific gravity 2.6. These two varieties differ from each other not only in density, but also in chemical properties, the former being much more easily attacked by alkalies than the latter. By solidification from fusion (dry way) only the variety of specific gravity 2.2 can be formed, while the

[1] Rose, *Philosophical Magazine*, xix., p. 32; Delesse, "Archives des Sciences," vol. vii., p. 190; Hunt, *American Journal of Science and Arts*, new series, vol. i., pp. 82, 182.

[2] Dana, *American Journal of Science*, vol. xx., p. 194, 1880.

variety 2.6 is formed only by slow deposit from solution (humid way).[1] Now, the quartz of granite is always of the variety 2.6, and therefore must have been formed in presence of water.

4. The several minerals of which granite is composed will not separate from a fused granitic magma on cooling ; but, on the contrary, fused granite solidifies into a highly-siliceous glass. The only answer to this, as well as to the preceding, is that the behavior of the granitic magma, when fused on a large scale and cooled slowly in the laboratory of Nature, is possibly different from its behavior when melted in small masses and cooled less slowly in *our* laboratories.

5. Crystals of quartz, feldspar, and mica, are frequently formed in Nature by the humid process, as, for example, in metamorphic rocks ; and have also been *artificially* formed by the same process by Daubrée, Senarmont, and others, as already stated (p. 223) ; but they have never been formed artificially by the dry way.

6. In nearly all rocks and minerals microscopic cavities are found indicating the conditions under which crystallization or solidification took place. If crystals are formed by sublimation, they contain *vacuous* cavities. If they are formed by solidification from fusion (dry way), and if gases are present, they may contain air-blebs ; but, if they crystallize slowly from a glassy magma, they contain spots of glassy matter, or *glass cavities*, as in slags and lavas. If they are formed by crystallization from solution, then they have *fluid cavities*, or liquid inclusions, as they are now usually called. Now, not only are these fluid cavities found in metamorphic rocks, but also in the quartz and feldspar of granite. "A thousand millions of these microscopic cavities in a cubic inch is not at all unusual ; and the inclosed water often constitutes one to two per cent. of the volume of the quartz."[2] Besides these fluid cavities, however, glass cavities are also found in the quartz and feldspar of granite. These facts point plainly to the agency of both heat and water in the formation of granite. Among the liquids thus inclosed in granite and other metamorphic rocks is often found *liquid carbonic acid.* This fact shows the great pressure under which solidification of the rock took place.

Even the temperature at which metamorphic rocks and granite solidified has been approximately determined by Mr. Sorby. The principle on which this is done is as follows : If crystallization from solution, or solidification in the presence of water, take place at *ordinary* temperatures, then the fluid cavities will be full ; but if at high temperatures, and the mass subsequently cools, then by the contraction of the contained liquid a *vacuous* space will be formed which will be larger, in proportion to the amount of contraction, and therefore to

[1] Recently quartz, specific gravity 2.6, has been formed under peculiar conditions by dry fusion. *American Journal of Science*, vol. xvi., p. 155, 1878.

[2] Sorby, *Quarterly Journal of the Geological Society*, vol. xiv., pp. 329, 453.

the temperature of solidification. Knowing, therefore, the relative sizes of the vacuole and the contained water, and the coefficient of expansion of the water and the rock, the temperature at which the cavity would fill (which is the temperature of solidification) may be calculated. Sometimes this temperature may be gotten by actual experiment, i. e., by heating until the cavity fills. By this method Mr. Sorby has calculated the temperature of solidification of certain metamorphic rocks of Cornwall as 392° Fahr., and of some granites as 482°, and others only 212°.

It seems almost certain, therefore, that most granites have not been formed by dry, igneous fusion. Yet that this rock has been in a liquid or pasty condition is perfectly certain from its occurrence in tortuous veins. Therefore it has been rendered pasty by heat in the presence of water under great pressures, such as always exist in deeply-buried strata. The weight of the superincumbent strata, or else pressure by folding and crushing of the strata, has forced it into cracks and great fissures.

What we have said of granite applies of course to the whole granitic group. Granitic rocks are often only the last term of the metamorphism of sediments; granite being produced from the more siliceous sediments, and dark syenites from the more basic impure clays. But we cannot stop with this group. It is certain that many if not all the rocks of the Trappean group also may be made by metamorphism of sediments. Many bedded diorites, dolerites, and felsites, are undoubtedly formed in this way, for the gradations can be distinctly traced into slates. Prof. Dana[1] has recently recognized this as so certain that he proposes the addition of the prefix *meta* to these to indicate their origin. Thus he recognizes a syenite and a metasyenite, a diorite and a metadiorite, dolerite and metadolerite, felsite and metafelsite, etc., and we might add granite and metagranite.

Many geologists push these views so as to include also even the true lavas. Deeply-buried sediments under gentle heat in the presence of water and pressure undergo incipient change and form metamorphic rocks; under greater heat become pasty and form granite, metasyenites, metadiorites, metafelsites, etc.; under still greater heat, increased probably, as Mallet suggests, by mechanical energy in crushed strata being converted into heat, become completely fused, and are then outpoured upon the surface either by the elastic force of the steam generated, or by the pressure and squeezing produced by the folding of the crust of the earth, so common in mountainous regions. According to this view, every portion of the earth's crust has been worked over and over again, passing through the several conditions of soil, sediment, stratified rock, metamorphic rock, and igneous rock, perhaps many times in the course of the geological history of the earth, and we look in vain for the primitive rock of the earth's crust.

[1] *American Journal of Science and Arts*, vol. xi., p. 119, February, 1876.

CHAPTER V.

STRUCTURE COMMON TO ALL ROCKS.

We have thus far given a brief description of the three classes of rocks, their structure and mode of occurrence. There are still, however, several important kinds of structure which are common to all these classes of rocks, and require description. These are *joints*, *fissures*, and *veins*. *Mountain-chains*, as involving all kinds of rocks and all kinds of structure, must be taken up last.

Section 1.—Joints and Fissures.

Joints.

All rocks, whether stratified or igneous, are divided, by cracks or division-planes, in three directions, into separable irregularly prismatic blocks of various sizes and shapes. These cracks are called joints. In *stratified* rocks the planes between the bedding constitute one of these division-planes, while the other two are nearly at right angles to this and to each other, and are true joints. In *igneous* rocks all the division-planes are of the nature of joints. In *sandstone* these blocks are large and irregularly prismatic; in *slate*, small, confusedly rhom-

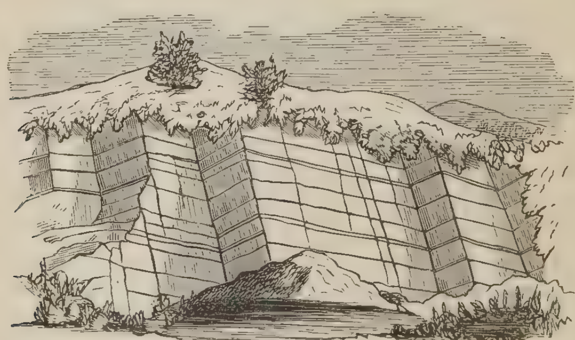


Fig. 196.—Regular Jointing of Limestone.

boidal; in *shale*, long, parallel, straight; in limestone, large, regular, cubic; in *basalt*, regular, jointed, columnar; in granite, large, irregularly cubic or irregularly columnar. On this account a perpendicular rocky

cliff usually presents the appearance of huge, irregular masonry, without cement.

The *cause* of joints is probably the shrinkage of the rock in the act of consolidation from sediments (lithification), as in stratified rocks, or

FIG. 197.—Granitic Columns.

in cooling from a previous condition of high temperature, as in the igneous and metamorphic rocks.

Fissures, or Fractures.

These must not be confounded with joints. Joints are cracks in the *individual strata* or *beds;* fissures are fractures in the *earth's crust*, passing through many strata, and even sometimes through many formations. The former are produced by shrinkage; the latter by movements of the earth's crust. Fissures, therefore, are often fifty or more miles in length, thirty to fifty feet in width, and pass downward to unknown but certainly very great depths.

Cause.—The cause of great fissures is evidently always movements, and usually foldings or wrinkling of the earth's crust, produced probably by contraction of the interior portions, as will be explained under Mountain-Chains, page 250. The natural tendency of such foldings would be to form a parallel system of fissures in the direction of the folds, and therefore at right angles to the direction of the folding force. Fissures are usually thus found *in systems parallel among themselves*, and to the axes of mountain-chains. Through such fissures igneous rocks in a fused condition are often forced, forming dikes and overflowing sheets. Besides the principal fissures just explained, Hopkins has shown that, in the case of the formation of mountains, there would be formed also other smaller fissures at right angles to these.

Often the walls on the two sides of a fissure do not correspond with each other, but one side has been pushed up higher or dropped down lower than the other. Such a displacement is called a *fault*, a slip, or dislocation. This may occur in fissures in any kind of rock, but is most marked and most easily distinguished in stratified rocks. When the

strata are sufficiently flexible to admit it, they are bent instead of broken, and a monocline is formed instead of a fault (Fig. 198). When the fissure is filled at the moment of its formation with fused matter from beneath, it is called a *dike*. When it is not filled at the moment of its formation with igneous injection, but *slowly* afterward with *other matter*, and by a *different process*, it is called a *vein*.

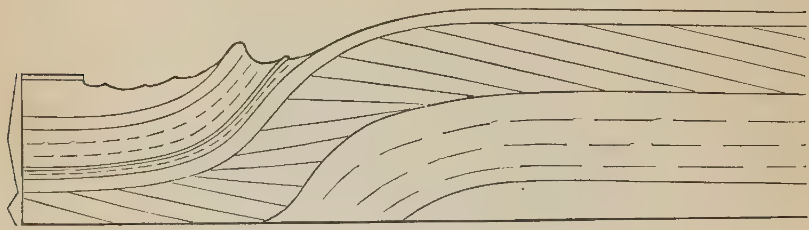


Fig. 198.—Section of Nutria-Fold, New Mexico (after Gilbert).

Faults.—In faults the extent of vertical displacement varies from a few inches to hundreds or even thousands of feet. In the Appalachian chain there occur faults in which the vertical dislocation is 5,000 to 20,000 feet. In Southwest Virginia, according to Rogers, there is a line of fracture extending parallel to the Appalachian chain for eighty miles, in which there is a vertical slip of 8,000 feet,[1] the Lower Silurian being brought up on one side until it comes in conjunction with the Lower Carboniferous on the other (Fig. 199). In Western Pennsylvania,

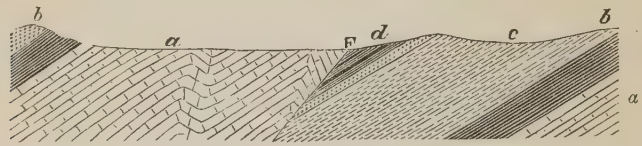


Fig. 199.—Fault in Southwest Virginia: *a*, Silurian; *d*, Carboniferous (after Lesley).

according to Lesley, there is another fault extending for twenty miles, in which the lowermost of the Lower Silurian is brought up on a level with the uppermost of the Upper Silurian, the whole Silurian strata being at this place 20,000 feet thick, so that one may stand astride of the fissure with one foot on the Trenton limestone (Lower Silurian), and the other on the Hamilton shales (Devonian).[2] On the north side of the Uintah Mountains there is a slip, according to Powell, of nearly 20,000 feet.[3] The Sevier Valley fault, Utah, may be traced partly as a slip, partly as a monocline, for 225 miles (Gilbert). On the west side

[1] Dana's "Manual," p. 399.
[2] "Manual of Coal," p. 147.
[3] "Exploration of Colorado River," p. 156.

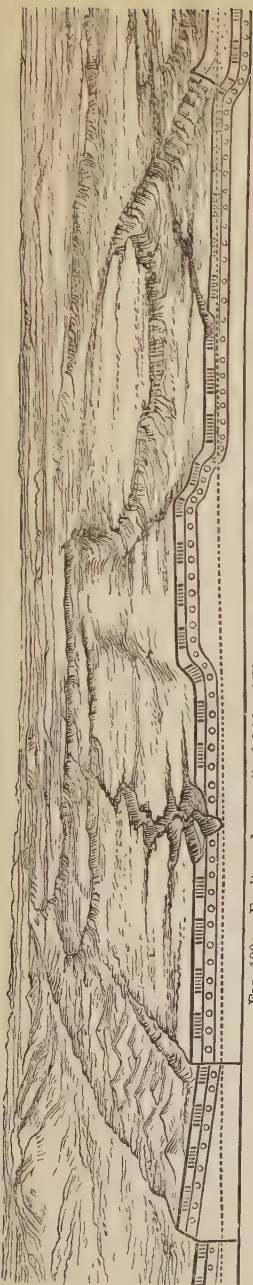


FIG. 199a.—Faults and monoclinal folds of Plateau region; section 90 miles long (after Powell).

of the Wahsatch range there is a fault of 40,000 feet[1] (King), and on the east side of the Sierra one of at least 15,000 feet.[2]

But nowhere on this continent, or perhaps in the world, are fissures and faults developed on so grand a scale as in the high Plateau region, i. e., the region bounded by the Wahsatch, the Uintah, and the Colorado Mountains. The whole of this elevated region is traversed by a system of north and south fissures, extending for hundreds of miles, by which the almost horizontal strata are broken into huge oblong prismatic blocks many miles wide. The slipping of these blocks, some to a higher and some to a lower level, with a difference of 1,000 to 5,000 feet, or even in some cases 12,000 feet, has given rise to the remarkable series of north and south cliffs, which, together with the equally remarkable east and west cliffs, due to erosion, to be described hereafter (p. 260), form so striking a feature of the scenery of this region. The accompanying section and perspective view (Fig. 199a), taken from Powell, shows three of the six which occur in 90 miles.

These fissures were formed by the elevation of the Plateau region, and are parallel to the axis of elevation; on each side of which they are arranged with wonderful regularity. They were formed in very recent geological times, probably late Pliocene and Quaternary,[3] and possibly reaching even into the present epoch, and are therefore little affected by erosion. Add to this the nakedness of the rocks and the horizontality of the strata, and it is easy to see what an admirable field is here afforded for the study of faults. If such slips were suddenly produced by violent convulsion, then,

[1] "Survey of the Fortieth Parallel," vol. i., pp. 728–746.

[2] Le Conte, *American Journal of Science*, vol. xvi., p. 101, 1878.

[3] Dutton, "Geology of the High Plateaus," p. 35.

at the time of formation, there must have been a steep (Fig. 200), or sometimes even an overhanging, escarpment (Fig. 199), equal to the displacement. In *some* cases there is such an escarpment or line of steep mountain-slope corresponding to the line of slip. In the Colorado Plateau region the north and south cliffs are produced by faults (Powell). The Zandia Mountains, New Mexico, are produced by a drop of 11,000 feet on the western side, leaving an escarpment still 7,000 feet high (Gilbert). The precipitous eastern slope of the Sierra and western slope of the Wahsatch are the result of faults. In the Basin Range region also many of the ridges are formed by faults. But in most cases there is no such escarpment, the two sides of the fault having been cut down to one level by subsequent erosion, so that the unpractised eye detects nothing unusual along the line of fracture and slip. In Fig. 200 the strong line *a a* shows the pres-

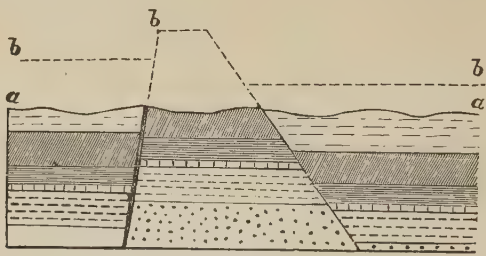


FIG. 200.

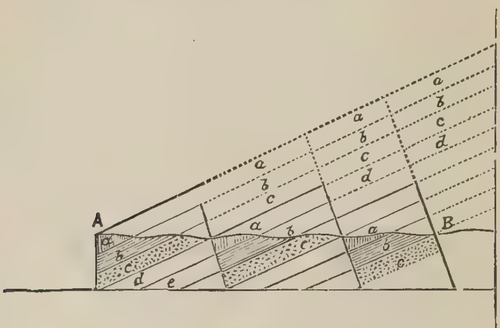


FIG. 201.—Strata repeated by Faults.

ent surface, while the dotted line *b b b* shows the surface after the displacement as it would be if unaffected by erosion. In many cases, however, it seems more probable that there never existed any such escarpment as represented in Fig. 200, but that the displacement was produced by a *slow, creeping motion*, or else by a succession of smaller sudden slips probably accompanied with earth-

quakes (p. 106), and thus that the slipping and the denudation have gone on together *pari passu*. In Fig. 243, on page 274, the upper part shows the great Uintah fault restored, while the lower part shows the actual condition of things produced by erosion.

FIG. 202.—Section through Portion of Plateau Region of Utah, showing a Succession of Faults (after Howell).

When faults occur in inclined outcropping strata, the same series of strata may be repeated several times, as in Fig. 201. In such a case, the observer walking over the surface of the country from *A* to *B*

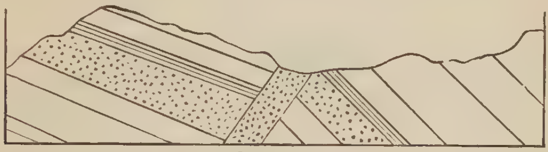


FIG. 203.—Fault with Change of Dip: *d*, dike.

might suppose here a series of nine strata, whereas there are but three strata, *a*, *b*, *c*, three times repeated. Fig. 202 is a natural section showing this. Sometimes the dip of the strata on the two sides of a fault are not parallel, the change of inclination being effected at the time of the displacement, as shown in Fig. 203. Upon the eroded surface of such dislocated strata, by subsequent subsidence, other strata may be unconformably deposited (Fig. 204).

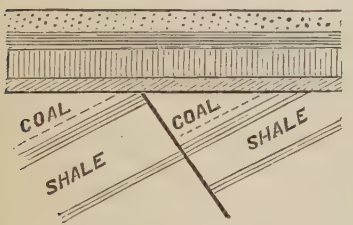


FIG. 204.—Unconformity on Faulted Strata.

Law of Slip.—In faults the plane of fracture is *sometimes vertical*, but much more generally it is more or less *inclined*. In such cases, in by far the larger number of great faults, the strata on the upper side (hanging wall) of the fracture have *dropped down*, while the strata on the lower side (foot-wall) have gone *up*, as in Figs. 205 and 206. This would probably be the case if, after the fracture, the relation of parts was adjusted by gravity alone. In some cases of strongly-folded strata, however, the hanging wall seems to have been pushed and made to slide upward over the foot-wall as if by powerful horizontal squeezing. This is the case with the great slip in Southwestern Virginia, represented in Fig. 199. Examples of this kind, however, are exceptional. In several hundred cases of great fissures, examined by Phillips, in

England, nearly all followed the law given above.[1] Fig. 205 is a section across Yarrow Colliery, in which all the slips follow this law. Of

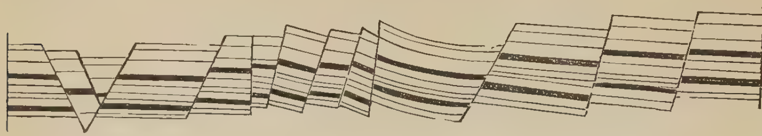


Fig. 205.—Section across Yarrow Colliery, showing the Law of Faults (after De la Beche).

the numerous slips figured by Powell, Gilbert, and Howell, as occurring in the Plateau and Basin Range region, nearly all follow this law. Fig. 206 is a section illustrating this fact.

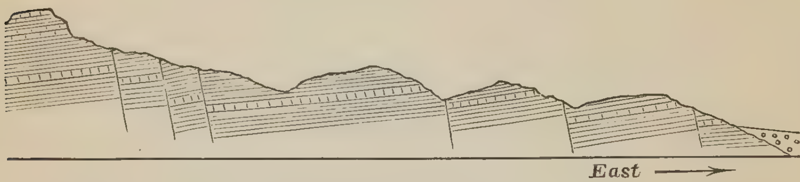


Fig. 206.—Section of Pahranagat Range, Nevada, showing the Law of Faults (after Gilbert).

Section 2.—Mineral Veins.

All rocks, but especially metamorphic rocks in mountain-regions, are seamed and scarred in every direction, as if broken and again mended, as if wounded and again healed. All such seams and scars, of whatever nature and by whatever process formed, are often called by the general name of *veins*. It is better, however, that dikes and so-called granite-veins, or all cases of fissures filled at the moment of formation by igneous injection, should be separated from the category of veins. True veins, then, are accumulations, mostly in fissures, of certain mineral matters usually in a purer and more sparry form than they exist in the rocks. The accumulation has in all cases taken place *slowly*.

Kinds.—Thus limited, veins are of three kinds: *Veins of segregation*, *veins of infiltration*, and great *fissure-veins*. These three, however, graduate into each other in such wise that it is often difficult to determine to which we must refer any particular case. Some writers make many other kinds, but these may be regarded as intermediate varieties.

1. *Veins of Segregation.*—In these the vein-matter does not differ greatly from the inclosing rock. Such are the irregular lines of granite in granite, the lines differing from the inclosing rock only in color or texture; also irregular veins of feldspar in granite or in gneiss. Under the same head belong also the irregular streaks, clouds, and blotches, so

[1] Phillips's "Geology," p. 35.

common in marble. In these cases there seems to be no distinct line of separation between the vein and the inclosing rock—*no distinct wall to the vein.* The reason is, these veins are not formed by the filling of a previously-existing fissure, but by the segregation of certain materials, in certain spots and along certain lines, from the general mass of the rock, either when the latter was in plastic condition from heat and water, or else by means of percolating water, somewhat as *concretions* of lime, clay, iron-ore, and flint, are formed in the strata (p. 188).

2. *Veins of Infiltration.*—Metamorphic rocks have, probably in all cases, been subjected to powerful horizontal pressure. Besides the wide folds into which such rocks are thus thrown and the great fissures thus produced, the strata are often broken into small pieces by means of the squeezing and crushing. The small fissures thus produced are often filled by *lateral secretion* from the walls, or else by slowly-percolating waters holding in solution the more soluble matters contained in the rocks. The process is similar to the filling of cavities left by imbedded organisms (p. 193), and still more to the filling of air-blebs in traps and lavas, and the formation of agates and carnelian amygdules (p. 216). In veins of this kind, therefore, a beautiful *ribbon-structure* is often produced by the successive deposition of different-colored materials on the walls of the fissure. Veins of this kind also, since they are the filling of a previously-existing fissure, have *distinct walls.* The filling consists most commonly of silica or of carbonate of lime.

3. *Fissure-Veins.*—These are fillings of the great fissures produced by movements of the earth's crust. When these fissures are filled at the time of formation by igneous injection, they are called *dikes;* but if subsequently with mineral matter, by a different process, to be discussed hereafter, they are *fissure-veins.* These veins, therefore, like dikes, outcrop over the surface of the country often for many miles, fifty or more. Like dikes, also, they are often many yards in width, and extend to unknown, but certainly very great, depths. Like dikes and fissures, also, they occur in parallel systems.

Characteristics.—The most obvious characteristics of the veins of this class are their *size*, their *continuity* for great distances and to great depths, and their occurrence in *parallel systems.* As the vein is a filling of a previously-existing fissure, the distinction between the vein and the wall-rock is usually quite marked. In many cases, in fact, the vein-filling is separated from the wall-rock by a layer of tenacious, clayey matter called a *selvage.* The selvage is probably formed by decomposition of the wall-rock in immediate contact with the vein, by circulating water. The *contents* of fissure-veins are also far *more varied* than those of other classes.

Metalliferous Veins.—Some metals, particularly *iron*, occur principally in great beds, being accumulated by a process already described

(p. 136). Others, especially *lead*, often accumulate in flat cavities between the strata, especially of limestone. But most metals occur in veins. All the kinds of veins mentioned above may contain metals, but the *segregative* veins are usually too irregular and uncertain, and the *infiltrative* veins too small, to be profitable. True, profitable metalliferous veins are almost always great *fissure-veins*. We will speak, therefore, only of these, and the further description of fissure-veins is best undertaken under this head.

Contents.—The contents of metalliferous veins are of two general kinds, viz., *vein-stuffs* and *ores*. The principal vein-stuffs are quartz, carbonate of lime (calc-spar), carbonate of baryta, carbonate of iron, sulphate of baryta (heavy spar), and fluoride of calcium (fluor-spar). By far the most common of these is *quartz*, and next is *calc-spar*. Often, however, the vein-stuff is an aggregate of minerals forming a true rock. Nearly the whole of a vein consists usually of vein-stuff. The *ore* exists in comparatively small quantities, sometimes forming a central *rib* or *sheet*, as if deposited last (Fig. 209) ; sometimes in irregular isolated masses called *bunches* or *pockets*, or in small strings, or grains, irregularly scattered through the vein-stuff and extending often a little way into the wall-rock.

The *chemical forms* in which metals occur are very various ; sometimes they occur as pure metal (as always in the case of gold and platinum, and sometimes in the case of silver and copper), but more commonly in the form of metallic sulphides, metallic oxides, and metallic carbonates. Of these the metallic *sulphides* are by far the most common. It is worthy of remark that all these forms are comparatively very insoluble. The same is true of the vein-stuffs.

Ribboned Structure.—The ribboned or banded structure, already spoken of under Veins of Infiltration, is very commonly found in great

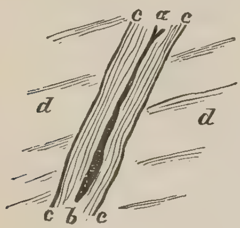


Fig. 207.

Fig. 208.

fissure-veins. This structure is as characteristic of veins as the columnar structure is of dikes. The layers on the two sides usually correspond to each other (Fig. 207) ; sometimes the successive layers are of different color, giving rise to a beautiful, striped appearance. Sometimes the successive layers on both sides are of different materials, as

in Fig. 208, in which the central rib, *d*, is galena, and *a a*, *b b*, *c c*, are successive layers of quartz, fluor, and baryta. Sometimes, in cases of quartz-filling, the layers are agate, except the centre, which is filled up

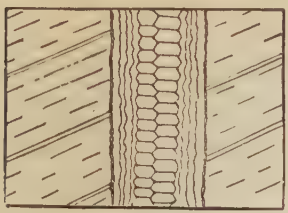


FIG. 209.

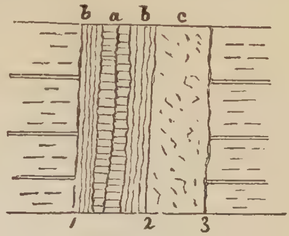


FIG. 210.

with a comb of interlocking crystals, as in Fig. 209. The same occurs often in amygdules, the last filling being crystalline. Sometimes there is evidence of successive openings and fillings, as in Fig. 210, where *a* represents quartz-crystals, interlocking in the centre and based on agate layers, *b b*, while *c* represents quartz with disseminated copper pyrites.

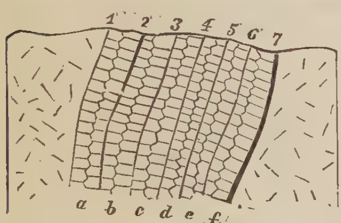


FIG. 211.

In this case it seems probable that 1 and 2 were the walls when the agate and quartz filling took place, and that afterward the fissure was reopened along 2, so that the walls became 2 and 3, and the new fissure thus formed was filled with cupriferous quartz. The same is well shown in Fig. 211, where *a*, *b*, *c*, *d*, *e*, *f*, are successive quartz-combs, separated by 2, 3, 4, 5, 6, which are clay selvages, and therefore old walls.

Irregularities.—Although more regular than other kinds, yet fissure-veins are also often quite irregular—sometimes branching, sometimes narrowing or pinching out in some parts and widening in others (Fig. 212), sometimes dividing and again coming together, and thus inclosing a portion of the wall-rock (Fig. 213). Such an inclosed mass of country rock in the midst of a vein is called a "*horse*." Many of these irregularities are probably the result of movements after the fissure was formed, or even after it was filled. Thus, if *a b c d* (Fig. 212) be one wall of an irregular vein, then it is probable that *a′ b′ c′ d′* was the original position of this wall; but, *before* it was filled, it slipped up to its present position. Or, an open fissure may pinch together in places by what is called *creeping* of the strata of the wall, i. e., a mashing and filling in by pressure of superincumbent weight. Again, movements may reopen a fissure *after* it is filled. In such cases, if the adhesion of the filling to the wall is strong, portions of the wall-rock

are torn away; and, if a second filling takes place, a "horse" is formed. Thus *a a a* and *b b b* (Fig. 208) represent the two original walls of an irregular vein; but subsequent movement reopened the fissure to *b′ b′ b′* and tore away the horse *H*, after which the vein was again filled. Also

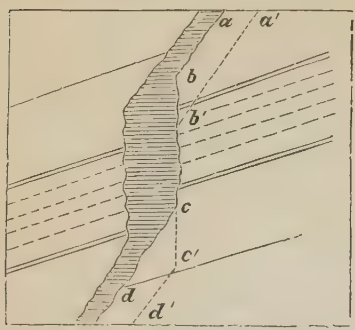


FIG. 212.—Irregularities in Veins.

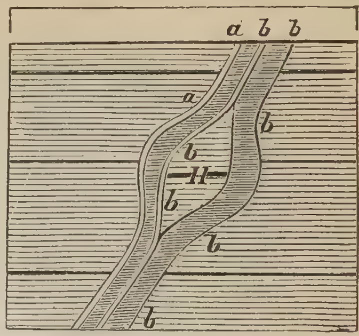


FIG. 213.—Irregularities in Veins.

crust-movements may form not only a single clean fissure, but sometimes many small, irregular fractures, with wall-rock between. The filling of these forms irregular veins in which vein-stuff is often inextricably mingled with country rock.

Veins, of course, *usually intersect* the strata; but in some cases where strata-planes are highly inclined the opening is between these planes, and the veins are, therefore, conformable with them.

Age.—The *relative* age of veins in the same region is determined in the same way as that of dikes, viz., by the manner in which they intersect each other; the intersecting vein being, of course, younger than the intersected vein. Thus in Fig. 214, which is a section of a hill-side in Cornwall, it is evident that the tin-vein, *a*, is the oldest, since it is intersected and slipped by all the others. The copper-vein, *b*, is older than the clay-filled fissure, *c*. There is a fourth fissure, *d*, newer than *a*, but its relation to *b* and *c* is not shown in the section.

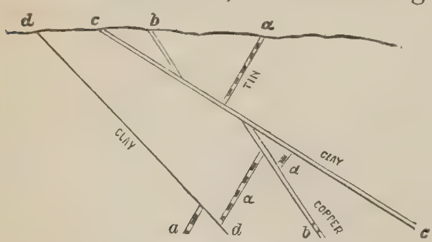


FIG. 214.

The *absolute* age of fissure-veins, or the geological period in which the fissure was formed, can only be determined by the stratified rocks through which it breaks. The lead-veins of Cornwall (*b b*, Fig. 216) break through the Cretaceous. Their fissures were probably formed by the changes or oscillations which closed the Cretaceous and inaugurated the Tertiary period. The auriferous veins of California break through the Jurassic; and, as there are good reasons for believing that the Sierras were formed at the end of the Jurassic, it is probable that these fissures

were formed at that time, by the foldings of the strata consequent upon the pushing up of this range. The *filling*, of course, was a slow, subsequent operation, but commenced then.

Surface-Changes.—Mineral veins seldom or never outcrop on the surface in the condition we have described them. On the contrary, there are certain changes which they undergo through the influence of atmospheric agencies, which render their appearance along their outcrop quite different from that of the same vein at some depth below. A knowledge of these changes is, of course, of the greatest practical importance. They are, however, extremely various, differing not only according to the metallic contents, but also according to the nature of the vein-stuffs, and therefore must be learned by observation in each country. We will give three of the most constant as illustrations.

Cupriferous Veins.—The original form in which copper seems to exist in veins is *copper pyrites*, a double sulphide of copper and iron ($CuFeS_2$). Now, along the *back* or outcrop of copper-veins, to a depth of thirty to sixty feet, the vein usually contains no copper at all, but consists of vein-stuff (more or less changed, according to its nature), among which are scattered masses of a dark reddish or brownish hydrated peroxide of iron, in a *light, spongy condition.* This peculiar form of peroxide of iron, so characteristic of the outcrop of copper-veins, is called by the Cornish miners *gossan*, and by the German and French miners *iron hat* (*eiserner hut; chapeau de fer*). Below the influence of atmospheric agencies the vein is in its original condition, i. e., consists of vein-stone containing disseminated masses of copper pyrites. Just at the junction of the changed with the unchanged vein—i. e., running along the back of the vein at a depth varying from thirty to sixty feet—occur rich accumulations of copper, as native copper, red and black oxides of copper, green and blue carbonates of copper, etc. These facts are illustrated by Fig. 215, which is a section of the Ducktown mines of Tennessee. The irregular line, *s s*, is the outline of a hill, along the crest of which the vein outcrops; the part *b* consists almost wholly of gossan, with only small masses of quartz-vein stuff; *a* is the rich accumulation of copper-ore, here about two or three feet thick; and *c* is the unchanged vein, consisting of vein-stuff, inclosing arsenical pyrites, and copper pyrites in very large quantities.

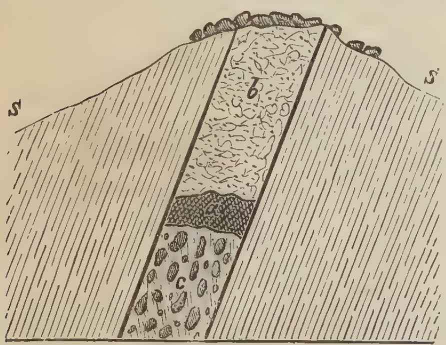


FIG. 215.—Ducktown (Tennessee) Copper-Vein, showing Surface-Changes (after Safford).

These phenomena may be explained as follows: There can be no doubt that the gossan represents copper pyrites, from which the copper has been entirely washed out, leaving the iron in an oxidized condition. Thus the whole of the copper from *b* (and probably from much more than *b*, for the process of denudation has gone on *pari passu* with the process of leaching) has been leached out and accumulated at *a*. Further, it is probable that the process was as follows: When copper pyrites is exposed to moist air, it slowly oxidizes into sulphates of iron and copper ($CuFeS_2+8O=FeSO_4+CuSO_4$). The *iron* sulphate (probably assisted by reaction with alkaline or earthy carbonates) quickly passes into ferric oxide and is left in a spongy condition, while the copper sulphate is carried downward. This much seems certain, but, by what subsequent process the copper takes all the forms actually found at *a*, is little understood, although it is probable that the carbonate is produced by the reaction, on the sulphate, of waters containing alkaline carbonate or bicarbonate of lime.[1]

Plumbiferous Veins.—The natural or original form in which lead occurs in veins is *sulphide* of lead, or *galena*. But along the backs or outcrops of lead-veins it is found more commonly as carbonate. The explanation seems to be as follows: Lead occurs mostly in veins intersecting, or in sheets between, strata of limestones. It is probable that the galena (PbS) is oxidized by meteoric agencies and becomes sulphate ($PbSO_4$), and then the sulphate, by reaction with the carbonate of lime derived from the wall-rock or from the calc-spar of the vein-stuff, becomes carbonate, thus: $PbSO_4+CaCO_3=PbCO_3+CaSO_4$. In proof of this process it is stated[2] that galena, thrown out of the old mines of Derbyshire among rubbish of limestone, has all, in the course of ages, been changed into carbonate.

Auriferous Quartz-Veins.—Gold is found either in quartz-veins intersecting metamorphic slates (quartz-mines) or in gravel-drifts in the vicinity of these (placer-mines). Originally it existed in the quartz-veins usually associated with metallic sulphides, particularly the *sulphide of iron* (pyrites). If the pyrites be dissolved in nitric acid, the gold is left as minute threads and crystals. Evidently, therefore, it exists in minute threads and crystals scattered through the pyrites. Now, when such a vein is exposed to meteoric agencies, the pyrites is oxidized, partly as soluble sulphate, and carried away, and partly as insoluble reddish peroxide, which remains.[3] The quartz-vein stone is, therefore, left in a honey-comb condition by the removal of the pyrites, and

[1] Bischof, "Chemical and Physical Geology," vol. iii., p. 509.

[2] De la Beche, "Geological Observer," p. 794.

[3] Probably the iron sulphide is oxidized to the condition of sulphate, then reduced to carbonate by water containing alkaline carbonate or bicarbonate of lime, and lastly peroxidized by exchanging carbonic acid for oxygen (Bischof).

more commonly stained of a rusty color by the peroxide. Among the cells of this rusty, cellular quartz the gold is found in minute, sharp grains, evidently left by the removal of the pyrites. Hence, in an auriferous quartz-vein, along the outcrop to a depth of thirty to sixty feet (i. e., as far as meteoric agencies extend), gold is found *free* in small grains among the cellular quartz; but below the reach of these agencies it is inclosed in the undecomposed pyrites.

Placer-Mines.—If a mountain-slope, along which outcrop auriferous quartz-veins, be subjected to powerful erosion by water-currents, then in the stream-beds will be found gravel-drifts, composed partly of the country rock and partly of the quartz vein-stone. Among the gravel will be found particles of gold, washed out from the upper parts of the veins. By the sorting power of water the heavy gold particles are apt to accumulate mostly near the bed of the gravel-deposit (bed-rock). These gravel-deposits are the *placers.* In these, the gold-particles, like the stone-fragments, are always *rounded* and *worn* by attrition.

Some Important Laws affecting the Occurrence and the Richness of Metalliferous Veins.

1. *Metalliferous veins occur mostly in disturbed* and *highly-metamorphic* regions, where the strata are tilted, and folded, and metamorphosed. The tilting and folding are necessary to the formation of *fissures;* and the conditions under which metamorphism takes place seem necessary for the subsequent *filling* with mineral matter. Mineral veins, therefore, occur mostly in *mountain-regions*, and in the vicinity of more or less obvious evidences of *igneous agency.* Lead-veins seem to be an exception to this rule. They are often found in undisturbed regions, where the rocks are entirely unchanged. The rich lead-mines of Illinois, Iowa, and Missouri, are notable examples, the country rock being horizontal, fossiliferous limestones of the Palæozoic era.

2. *Metalliferous veins occur mostly in the older rocks.* In Great Britain, for example, no profitable veins occur above the *Trias.* This rule, which was regarded as of great importance by the older geologists, is not so regarded now. There seems to be no close connection between the occurrence of metalliferous veins and simple age alone; the connection is rather with metamorphism. Metamorphism, as we have seen, (p. 223), is most common in the older rocks, and becomes more and more exceptional as we pass upward. The occurrence of metalliferous veins follows the same law. But when the newer rocks *are* metamorphic, they are as likely to contain veins as are rocks of the older series. The metalliferous veins of California occur in Jurassic, Cretaceous, and even Tertiary strata; but these strata are there highly metamorphic, and

strongly folded. In Bohemia, also, and elsewhere, metalliferous veins occur in the higher series (Phillips, p. 549).

3. *Parallel* veins are apt to have *similar* metallic contents, while veins running in different directions (unless sometimes at right angles) are apt to contain different metallic contents. Thus, the nearly east-and-west lodes of Cornwall, *a a a* (Fig. 216), contain tin and copper, while the

Fig. 216.—Map of Cornwall: *a*, tin and copper; *b*, lead and iron.

north-and-south courses, *b b*, contain lead and iron. The auriferous veins of California are parallel to each other and to the Sierras, except a few smaller ones, which are at right angles to these. The reason of this rule is, that parallel fissures belong to the same system, and were therefore formed at the same time, broke through the same strata, and were filled under similar conditions, and therefore with the same materials; while fissures running in different directions (unless in some cases at right angles, p. 229) were probably formed at different times, broke through different strata, and were filled under different conditions. Thus, the east-and-west veins of Cornwall break only through the Trias, while the north-and-south veins break through the Cretaceous. The auriferous veins of California all break through the Jurassic; they, or their fissures, were all produced at the same time, viz., at the time of pushing up of the Sierras.

4. A change of country rock of an outcropping vein is apt to determine some change, either in the contents or in the richness of the vein. Nevertheless, there is not that close connection between the nature of the country rock and the vein-contents which obtains in infiltrative veins. The reason is, that infiltrative veins derive their contents entirely from the wall-rock on either side, while fissure-veins derive their contents from *all* the strata through which they break, even to great depths, and especially from the deeper strata. The nature of the sur-

face or country rock is, therefore, only *one* factor, determining the vein-contents.

5. Metallic veins are usually richer near their point of intersection with granite or with an igneous dike, especially if the strata have suffered metamorphism. This shows the influence of such heat as is present in metamorphism, in determining the metallic contents.

6. If two veins cross each other, especially if at small angle, one or both are apt to be richer at the point of crossing. No sufficient reason has been given for this law. It is probably due to the reaction of waters bearing different materials circulating in the two fissures.

7. Since veins are the fillings of fissures, they are often slipped by each other or by dikes or by simple unfilled fissures. If a metalliferous vein is thus slipped, according to the law of slips already given (p. 233) the foot-wall of the vein has usually gone upward, and the hanging wall dropped downward. The great importance of this law in practical mining is sufficiently obvious. All the slips of Fig. 214, except that made by the fissure *c*, follow this law.

8. *The surface-indications* are to be learned by attentive observation in each case. We have already given these in the case of copper, lead, and gold.

Theory of Metalliferous Veins.

Our knowledge of the conditions under which, and the chemical process by which, fissures have been filled with mineral matter, is yet, unfortunately, very imperfect. Many vague and crude theories have been proposed. Some have supposed that they have been filled in the manner of dikes and granite veins, by igneous injection; others, that these fissures, opening below into the regions of incandescent heat, have been filled by *sublimation*, i. e., by vaporization of certain materials and their condensation in the fissures above. Some suppose that electric currents, such as are known by observation to traverse certain veins, have been the chief agents in the transference and accumulation of the mineral matter. Still others have thought that great fissures have filled in the same manner as the smaller fissures, and cavities of every kind found in the rocks, viz., by infiltration of soluble matters from the fissured rocks. There is certainly considerable analogy between small infiltrative veins and great fissure-veins in their mode of formation; yet there is a decided difference. The fillings of infiltrative veins are derived, in each part, entirely from the bounding rock on either side. The fissure is filled by a *lateral secretion* from its walls; the broken rocks heal themselves "by first intention" by means of a plasma oozing from the sides. But great fissure-veins derive their contents in each part from *all* the strata to great depths, and especially from the deeper strata. Hence the contents of these veins are far more varied.

Outline of the Most Probable Theory.—The contents of mineral veins seem to have been deposited from *hot alkaline solutions* coming up through fissures ; in other words, from *hot alkaline springs.* We will attempt to show this first for the *vein-stuffs*, especially quartz, and then for the *metallic ores*, especially the metallic sulphides.

Vein-Stuffs.—1. *They were deposited from solutions.* (*a.*) The *ribbon-structure* and the interlocked crystals (Fig. 211) suggest at once successive deposition from solution, especially as a similar structure occurs in the fillings of cavities of all kinds, which could not have been filled in any other way. (*b.*) Quartz is by far the most common of all vein-stuffs. Now, as already explained (p. 225), there are two varieties of silica—one having a specific gravity of 2.2, the other 2.6. The dry way produces only quartz-glass, which has a specific gravity of 2.2, while the variety of specific gravity 2.6, or true quartz, cannot be formed except by the humid way.[1] In fact, this variety, as far as we know, is always produced by *slow* deposition from solution. Now, the quartz of veins is always the variety 2.6, and therefore was produced by slow deposit from solution. The beautiful crystals so often found in veins could be produced in no other way. (*c.*) We have already seen (p. 218) that *fluid cavities* are a proof of formation by humid process. Now, such fluid cavities are especially abundant in vein-stuffs generally. They are best seen in quartz-vein stuffs, because of their transparency. (*d.*) Not only quartz, but many other minerals found among vein-stuffs are of such nature that it is difficult or impossible to understand how they could have been formed except by the humid way, as they will not stand fusing temperature.

2. *The solutions were hot.* (*a.*) Fissures running deep into the interior of the earth could hardly remain empty of water. But from their great depth the contained waters must be *hot.* The solvent power of water, when heated to high temperature under pressure, is well known. Scarcely any substance wholly resists it. (*b.*) The *fluid cavities* found in quartz and other vein-stuffs are not usually entirely filled, but contain a small *vacuous space.* Such a vacuous space indicates (p. 226) that the inclosed liquid was at high temperature at the time of being inclosed, and has since contracted on cooling. By heating the mineral until the cavity fills and the vacuous space disappears, we ascertain the temperature of deposit. Now, by this process the temperature of deposit of vein-minerals has been ascertained to vary from ordinary temperatures even up to 300° and 350°.[2] (*c.*) The invariable association of metalliferous veins with metamorphism demonstrates the agency of heat.

3. *The solutions were alkaline.* Alkaline carbonates and alkaline

[1] Recently under peculiar conditions crystallized quartz of specific gravity 2.6 has been formed by dry fusion.—*American Journal of Science*, vol. xvi., p. 155, 1878.

[2] Sorby, *Quarterly Journal of the Geological Society*, vol. xiv., p. 453, *et seq.*

sulphides are the only natural solvents of quartz, the commonest of vein-stuffs. Moreover, when these waters contain excess of carbonic acid, as is almost always the case, they dissolve also the carbonates of lime, baryta, iron, etc., the next most common forms of vein-stuffs. In California and Nevada such alkaline carbonate and alkaline sulphide springs abound, and are daily depositing silica (quartz) and carbonates of lime and of iron, and even in some cases filling fissures.

Metallic Ores.—There seems no reason to doubt, then, that, in most cases at least, vein-stuffs have been deposited from hot alkaline solutions. Now, it is evident, from their intimate association with the vein-stuffs, that the *metallic ores* must have been deposited from the same solution. The exact nature of the solvent and the chemical reaction is still very doubtful. We may imagine many by either of which the deposit might take place: 1. *Metallic sulphides* are by far the most common form of *ore*, and even when other forms exist we may in many cases trace them to sulphide as their original form (p. 239, *et seq.*). But metallic sulphides are slightly soluble in alkaline sulphides, and these latter are often found associated with alkaline carbonates in hot springs, as in California and elsewhere. Such waters would hold in solution silica, carbonates of lime, etc., and metallic sulphides, and, coming up through fissures, would deposit them *by cooling*. Or, 2. Alkaline carbonate waters holding in solution silica and lime carbonate for vein-stone, and also containing alkaline sulphide, *meeting* and mingling in the same fissure with *other* waters containing metallic sulphates, by reaction would precipitate metallic sulphides ($NaS + MSO_4 = NaSO_4 + MS$). This seems to be the reaction by which the inky waters of some of the hot springs of the California geysers are formed. Or, 3. The alkaline carbonates still remaining for vein-stone, metallic *sulphates*, in solution in the same waters *with organic matter*, would be reduced to the form of metallic sulphide, which, being insoluble, would be deposited.[1] Or, 4. Alkaline sulphide waters holding metallic sulphides and organic matters in solution—the acids of organic decomposition (humus acids) would neutralize the alkalinity and deposit the metallic sulphide. For greater clearness we annex a table expressing these processes:

$$\text{Alk.}CO_3 + HCO_3 + \left\{ \begin{array}{llll} \text{Alk.S} + \text{MS in sol}^{n} & \text{deposit} & \mathit{MS} & \text{by } \mathit{cooling.} \\ \text{Alk.S} + MSO_4 \text{ meeting} & \text{"} & \mathit{MS} & \text{" } \mathit{reaction.} \\ MSO_4 + \text{org}^{e} \text{ mat}^{r} & \text{"} & \mathit{MS} & \text{" } \mathit{reduction.} \\ \text{Alk.S} + \text{MS} + \text{org}^{e} \text{ mat}^{r} \text{ in sol}^{n} & \text{deposit} & \mathit{MS} & \text{by } \mathit{neutralization.} \end{array} \right.$$

There are many difficulties in the way of every attempt to place these reactions in a clear and distinct form, but in spite of these diffi-

[1] It might at first seem that there is a chemical difficulty in this case—that metallic sulphate cannot coexist in solution with alkaline carbonate, but would be precipitated as metallic carbonate. But it is evident that this reaction would not take place in a weak metallic solution, in the presence of *excess of carbonic acid*, since in this case the metallic carbonate is *soluble*.

culties there seems little reason to doubt that great fissures have been filled by deposit from hot alkaline waters holding various mineral substances in solution. The more *insoluble* substances are deposited in the vein, while the more *soluble* reach the surface as mineral springs.

This view is powerfully supported by the phenomena of hot alkaline springs in California and Nevada. The Steamboat Springs, near Virginia City, Nevada (so called from the periodic eruption of hot water and steam), come up through fissures in comparatively recent volcanic rock. The waters are strongly alkaline, and deposit silica in abundance. By this deposit the fissures are gradually filling up and forming veins. Some fissures are now partially and some entirely filled. The ribbon-structure in some cases is perfect. Moreover, sulphides of several of the metals, viz., iron, lead, mercury, copper, and zinc, have been found in the quartz-vein stuff. Here, then, we have true metalliferous veins forming under our very eyes.[1] So also at Sulphur Bank, Lake County, California, hot alkaline sulphide waters, coming up from beneath, deposit both silica and cinnabar in small, irregular fissures and cavities, forming quartz-veins containing cinnabar. The deposit is so recent that the silica is still in a soft, hydrated condition, which cuts like cheese.

After this general discussion of the theory of metalliferous veins, we are now in position to state more clearly their mode of formation. Meteoric waters, circulating in the interior of the earth in any direction—downward, upward, or laterally—deposit slightly soluble matters in their course, in cracks, cavities, or great fissures, forming fossil casts, geodes, amygdules, infiltration-veins, and fissure-veins. As to *direction*, the *up-coming* waters, especially in metamorphic and volcanic regions, deposit most freely, because they are hot and often alkaline, and therefore most powerful solvents, and, of course, cool gradually on approaching the surface. But that downward percolating waters may also deposit metallic ores is proved by the fact that these are sometimes found depending, like stalactites, from the roofs of cavities.[2] As to the different *kinds* of veins, those of *great fissures* are most prolific, because these fissures are the highways of water from the heated depths. But every kind of water-way will receive deposits; and, as the kinds of these are infinitely various and pass by insensible gradations into each other, so also will be the veins which fill them. The *open* fissure is the easiest and therefore the most traveled highway. In these, therefore, we have the most perfect type of veins, with their banded structure and their selvages, their great size and continuity. But in many cases crust-movements produce only *incipient* fissures, i. e., a loosening of the rock-cohesion, along planes affected

[1] Arthur Phillips, *American Journal of Science*, vol. xlvii., p. 194; and *Philosophical Magazine*, 1872, vol. xlii., p. 401.

[2] Schmidt, *American Journal of Science*, vol. xxi., p. 502, 1881.

with a multitude of small cracks, with country rock between. These loosened planes become also water-ways, and, by deposit, form those irregular veins so common everywhere, but especially in the cinnabar-veins of California. Or, again, crust-movements may produce not *clean open* fissures, but rather planes of shattered rock like fissures filled with rubble. Deposit in such a water-way forms a breccia of country rock, cemented with vein-stuff. Or, again, in certain country rocks soluble in water, especially limestones, the rock is dissolved along the water-way, and the vein-stuff deposited *pari passu*, giving rise to what are called substitution-veins. In short, once conceive clearly that mineral veins are filled water-ways, and all these complex phenomena solve themselves. Even porous rocks like sandstones, because of their porosity, become the depositaries of vein-stuff, though not in paying quantities, except along lines or planes where water-transit is more easy and abundant. Examples of such deposits are found in the silver-bearing and copper-bearing sandstones of Utah and New Mexico.[1]

Thus there seems no longer any room for doubt that metalliferous veins are deposits from solutions in water-ways of any kind, but mostly from hot alkaline solutions coming up through great fissures. It is only the exact chemical reaction which is yet obscure. The work of the geologist is all but complete; the problem must now be turned over to the chemist. It may be interesting, however, before leaving this subject, to consider separately the auriferous veins of California, and apply to them the principles set forth above.

Auriferous Veins of California.—Gold is one of the most insoluble of substances, and the occurrence of this metal in veins has always been regarded as a difficulty in the way of the *solution theory*. The only free solvent of gold is a solution of *free* chlorine; but this does not exist in Nature. Nevertheless, gold is known to be *slightly* soluble in the salts, especially the persalts of iron. These salts, especially the sulphate and *persulphate* of iron, are the probable solvents of gold. There is also a silicate of gold, which, according to Bischof, is slightly soluble under certain conditions.

There is abundant evidence that the auriferous quartz-veins of California have been deposited from *hot solutions*. These veins exhibit in many cases the characteristic *ribbon-structure*. They exhibit also the *water-cavities* characteristic of deposits from solutions, and the *vacuous spaces*, indicating that the solutions were *hot*. By actual experiment,[2] the *temperatures* at which the vacuous spaces disappear, and therefore at which the deposit took place, have been ascertained—being 180°, 212°, 350° F., and even more. Again, there can be no doubt that the associated metallic sulphides were deposited from the same solutions as the vein-stuffs, for they are completely inclosed in the latter. But the

[1] Cazin, Newberry, etc., "Report on Nacimiento Copper-Mines of New Mexico."

[2] Arthur Phillips, ibid.

gold, as already stated (p. 240), exists as minute crystals and threads of metal *inclosed in the sulphide of iron*, and must therefore have been deposited from the same solution as the iron. It seems most probable that the gold was dissolved in a solution of sulphate or persulphate of iron, and that the sulphate was deoxidized, and became insoluble sulphide and precipitated; and that the gold thus set free from solution was entangled in the sulphide at the moment of the precipitation of the latter.

There are some phenomena connected with the occurrence of gold in the iron sulphides of the *deep placers* which seem to prove the truth of this view.[1] The deep placers of California are gravel-drifts in ancient river-beds, covered up by lava-flows 100 to 200 feet thick. These placers

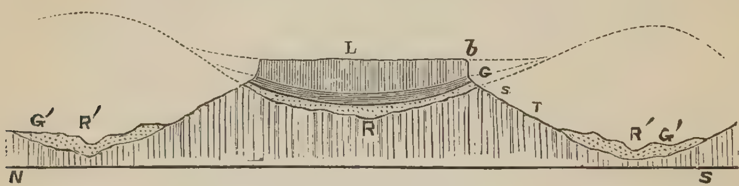


FIG. 217.—Section across Table Mountain, Tuolumne County, California: *L*, lava; *G*, gravel; *S*, slate; *R*, old river-bed; *R'* present river-bed.

are worked by running tunnels beneath the basaltic lava until the river-gravel is reached. Now, the waters percolating through these lava-flows and reaching the subjacent gravels are *charged with alkali* from the lava. These alkaline waters are also charged with *silica* from the same source. Hence, the *drift-wood* of these ancient rivers has all been silicified by these siliceous waters. The gravels are also in many places cemented by the same material. These percolating waters have evidently also contained *sulphate of iron;* for in contact with the silicified wood is often found iron sulphide. Thus, while the wood decayed it was partly replaced by silica and partly by iron sulphide produced by deoxidation of the sulphate by organic matter (p. 193). The gravel has also in some places been cemented by iron sulphide reduced from solution in a similar way. Now, both in this petrifying and in this cementing sulphide of iron is found (by solution in nitric acid) *gold:* sometimes in *rounded grains*, and therefore simply inclosed *drift-gold;* but also sometimes in *minute crystals and threads*, exactly as in the sulphide of the undecomposed quartz-vein. Evidently, this gold has been deposited from a *solution of sulphate of iron* at the moment of the reduction of the latter to a sulphide. The process was probably as follows: Percolating water oxidized iron sulphide and took it into solution as sulphate. This solution coming in contact with *drift*-gold dissolved it, but, subsequently, coming in contact with decaying or-

[1] Arthur Phillips, ibid.

ganic matter, was again deoxidized and deposited as sulphide; and the gold crystallizing at the same moment is inclosed.[1] If these waters had circulated through a fissure, we would have had an auriferous quartz-vein. In fact, this may be regarded as a sort of horizontal vein.

We conclude, therefore, that metalliferous veins have been deposited from hot alkaline waters, circulating through fissures, and that in the case of auriferous veins the solvent of the gold was sulphate of iron, and the sulphate was deoxidized by organic matter in the same solution, the gold and the iron crystallizing at the same moment, one as metal, the other as sulphide.[2]

Gold is sometimes found in pure quartz without the sulphide of iron. In these cases it may have been in solution in alkaline water as silicate of gold, as suggested by Bischof. There is a silicate of gold which may be made by artificial means. It is slightly soluble under certain conditions.[3]

Nuggets.—It is well known that, although gold exists in the iron sulphide of the unchanged vein only in minute, even microscopic, crystals and threads, yet in the changed upper portions of the vein it exists in quite visible particles, and often in large *nuggets* weighing several ounces, or even rarely several pounds. This fact is additional evidence that sulphate of iron is the natural solvent of gold. There can be no doubt that these larger grains and nuggets result from the coalescence of all the minute particles, contained in a mass of sulphide, into one or more larger masses. By meteoric agencies, as already explained (p. 240), the sulphide is oxidized into sulphate, and the gold redissolved. From this solution it crystallizes into one mass, as the solution concentrates by losing its sulphuric acid and changing into peroxide. In the case of large nuggets, the gold is probably in some way deposited constantly at the same place from a similar solution bringing gold for a long time.

Illustrations of the Law of Circulation.—We have said that the iron sulphate comes from oxidation of sulphide, but also the sulphide from the deoxidation of the sulphate. This is only another example of a perpetual cycle of changes. Again, the gold in the veins is leached from the strata; the strata doubtless received it from the sea, for small quantities of gold have been detected in sea-water; but, again, doubtless the sea received it from the rocks, and this brings us to another perpetual cycle of changes.

But in the midst of all these changes there has evidently been an increasing concentration and availability of gold and other metals. In the strata the quantity is so small as to be undetectible; it is thence carried and concentrated in veins in a more available form; it is next set free along the backs of these veins in a still more available form;

[1] Arthur Phillips, ibid. [2] See APPENDIX.
[3] "Chemical and Physical Geology," vol. iii., p. 535.

it is last carried down by currents along with other materials, neatly sorted, and deposited in *placers* in a form the most available of all.

SECTION 3.—MOUNTAINS: THEIR STRUCTURE AND ORIGIN.

Mountains are the glory of our earth, the culminating points of scenic beauty and grandeur. They are so because they are also the culminating points, the theatres of the greatest activity, of all geological agencies. The study of mountain-chains, therefore, must ever be of absorbing interest, not only to the painter and the poet, but also to the geologist. A thorough knowledge of their structure, origin, and mode of formation, would undoubtedly furnish a key to the solution of many problems which now puzzle us; but their structure is as yet little known, and their origin still less so.

Mountain-Origin.

The general cause of mountain-chains (as in fact of all igneous phenomena) is the "reaction of the earth's hot interior upon its cooler crust." Mountain-chains seem to be produced by the secular cooling, and therefore contraction, of the earth, *greater in the interior than the exterior;* in consequence of which, the face of the old earth is become wrinkled. Or, to express it a little more fully, by the greater interior contraction, the exterior crust is subjected to enormous lateral pressure, which crushes it together, and swells it upward along certain lines, the strata, by the pressure, being at the same time thrown into more or less complex foldings. These lines of upswelled and folded strata are mountain-chains. The first grand forms thus produced are afterward chiseled down and sculptured to their present diversified condition by means of aqueous agency. Thus much it was necessary to say of the origin of chains, in order to make the account of their structure intelligible. The theory of their origin will be given more fully hereafter.

General Form.

The term "mountain" is loosely used to express every considerable elevation above the general level of the country, whatever be its extent and mode of origin. It is applied equally to a complex *system of ranges,* formed at different times, such as the Andes, the Rocky Mountain, or the Appalachian system; or to each component *range* of such a system, such as the Coast Range, the Sierra, or the Wahsatch; or to each component *ridge* of such a range, or even to the separate peaks on these, whether formed by volcanic ejections or by erosion. In this work we shall call an aggregate of ranges formed at different times a *mountain system or chain.* Each primary component of such a system, formed by *one earth-throe* (monogenetic) we shall call a *range.* The components of these, again, whether formed by erosion or by foldings, we shall call *ridges.* Isolated *peaks,* whether of erosion or

volcanic ejection, are so obviously distinct and subsequent in their origin that they need not trouble us in this discussion.

A mountain system, therefore, is an elevated region of great extent and very complex in form, in structure, and in origin. For example, the American Cordilleras is a great bulge of the earth's surface, 10,000 miles long, in some parts 1,000 miles wide, and many thousand feet high, composed of several parallel ranges, formed at widely different times, and now separated by great valleys. In North America, the most conspicuous of these parallel component ranges are the Coast Range, the Sierra, and the Wahsatch, separated by the San Joaquin plains and the Great Basin. Each one of these ranges is composed of a number of *ridges*, separated by smaller *longitudinal* valleys, while the ridges, in their turn, are serrated with peaks, by the *transverse* valleys which trench their flanks. Similarly, the Appalachian *system* is composed of several ranges—e. g., the Blue, the Alleghany, and the Cumberland—separated by the great valleys of Virginia and East Tennessee; and each of these ranges is composed of subordinate ridges and peaks.

Such is the simplest ideal of the form of a mountain-chain; but in most cases this ideal is far from realized. In many cases the chain is a great plateau, composed of an inextricable tangle of ridges and valleys of erosion, running in all directions. In all cases, however, the erosion has been immense. Mountain-chains are the great theatres of erosion, as they are of igneous action. As a general fact, all that we see, when we stand on a mountain-chain—every peak and valley, every ridge and cañon, all that constitutes scenery—is wholly due to erosion.

Now, in any discussion of the structure and mode of formation of mountains we are mainly concerned with *ranges*. For, on the one hand, the adding of range to range in the formation of a *polygenetic system* adds no new element to the discussion, while, on the other, subordinate *ridges and peaks* are evidently the result of a subsequent process of erosion or of faulting, and therefore fall into the category of mountain-*sculpture*, not of mountain-*formation*.

Mountain-Structure.

The simplest idea of a mountain-range is that of a single fold of thick strata. Such a simple range is shown in Fig. 218, which is a generalized section of the Uintah Mountains, taken from Powell. But, more commonly, mountains, even when they are composed wholly of stratified rocks, consist of many folds, sometimes open, as in the Jura Mountains (Fig. 219), but more often closely pressed together. This is admirably illustrated in the following section of the Coast Range of California (Fig. 220), and also in the section of the Appalachian, on page 254 (Fig. 225). The manner in which mountains are formed is very evident in such cases. Such mountains cannot be formed except by a mashing together of the strata horizontally.

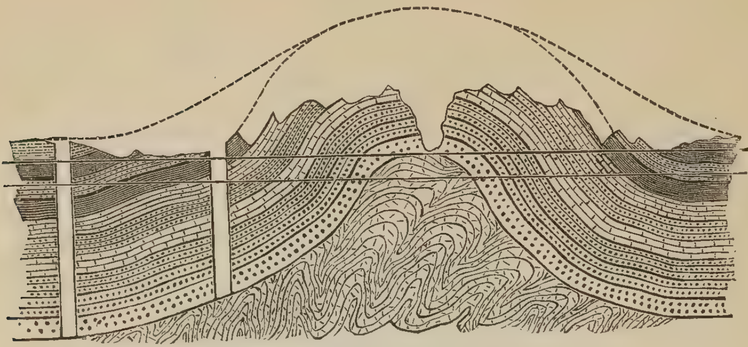


FIG. 218.—Ideal Section across the Uintah Mountains (after Powell).

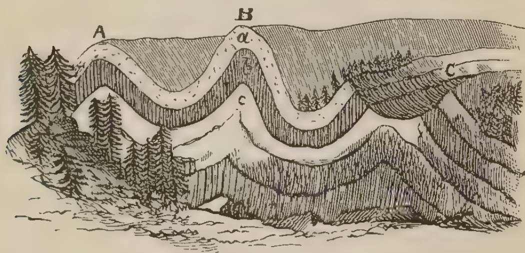


FIG. 219.—Section of the Jura Mountains.

FIG. 220.—Section of Coast Range, showing Plication by Horizontal Pressure.

But most great mountain-ranges, as shown in Fig. 221, consist of a *granite axis*, *g*, coming up from beneath and appearing at the surface along the crest and forming the peaks, flanked on either side by tilted strata, *a*, *a*, usually of enormous thickness, and corresponding on the two sides. Sometimes several series of unconformable strata on the flanks show that the range has been formed by successive upheavals (Fig. 222). The succession of events represented by this figure are: 1. The strata *a*, *a*, were deposited; 2. *a*, *a*, were uptilted and the mountain formed; 3. The strata *b*, *b*, were deposited horizontally, and therefore unconformably, on *a*, *a*; 4. The mountain-axis was pushed up higher, so as to tilt *b*, *b*, also; 5. *c*, *c*, were then deposited unconformably on *b*, *b*;

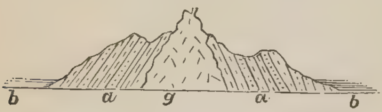


FIG. 221.

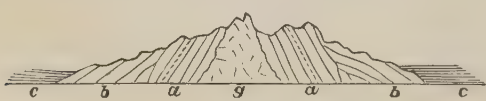


FIG. 222.

and, finally, 6. The whole was raised bodily, so as to expose *c*, *c*, but without tilting them.

Now many geologists seem to regard these two kinds of mountains, viz., those composed only of folded strata, and those with granite axis, as essentially different, and formed in different ways. Mountains of the latter class, they seem to think, were formed by a force acting *vertically*, pushing the granite axis *through the broken strata* to its present highest position along the crest. But it is far more probable that the stratified rocks and the subjacent granite were all pushed up by horizontal pressure into a fold, and the strata were afterward removed by erosion, leaving the harder granite as a crest. This is shown in the ideal section, Fig. 223, in which dotted lines represent the part removed by erosion. In many ranges, as, for example, in the Sierra, patches of the flanking strata are still left on the summits.

FIG. 223.—Ideal Section showing Exposure of Granite by Erosion.

Thus, then, mountain-ranges are all formed in the same general way, viz., by horizontal crushing. Sometimes they consist of a single fold, more often of many close folds; sometimes the strata are little changed, sometimes they are greatly metamorphosed; sometimes they are little eroded, sometimes very deeply eroded. The combination of these various conditions gives rise to a great variety of kinds: 1. If it consist of a single fold and the strata be unchanged, then we have the simplest conceivable range, as in the Uintah Range, Fig. 218. 2. But if the strata be greatly changed and deeply eroded, then the upper part of the fold is removed, and the completely metamorphic granite is exposed along the crest, and we have a case like Figs. 221 and 223. 3. If the range consist of many folds and the stratification be not destroyed by metamorphism, then we have cases like the Jura (Fig. 219), the Coast Range (Fig. 220), and the Appalachian (Fig. 225). 4. Lastly, if ranges like the last be greatly metamorphosed and deeply eroded, then we have the common case represented by Fig. 224. This may, perhaps, be regarded as the best type of a *great mountain-range.* It represents strata strongly folded and deeply denuded. But the *most-folded* and *least-changed* upper portions of the strata have been removed, and the very metamorphic and less-folded deeper portions are

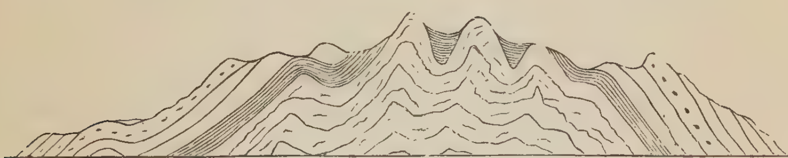


FIG. 224.—Ideal Section of a Mountain-Range.

exposed along the axis. The axis in this case, also, is represented as gneiss (i. e., a granite in which the original strata are still imperfectly visible), in order the better to bring out the real structure. But carry the process of metamorphism one step further, and the foldings of this part disappear, and we have a range of the type represented in Fig. 221. In fact, it is probable that many mountains which consist only of granite axes and tilted strata corresponding on each side, and therefore seem to be but *one fold*, were really originally of *many close folds*, only these have been carried away by erosion.

In still other ranges the constituent strata are overlaid by immense ejections of liquid matter, which conceal the true structure of the mountain. The Cascade Range is perhaps the most remarkable example of this.

As a general rule the degree of mashing, and therefore of folding, is greatest near the axis, and gradually passes into gentler and gentler undulations as we leave this line. This is strikingly seen in the Appalachian. Fig. 225 is a simplified section of this chain, in which each

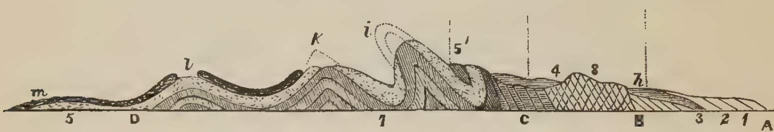


FIG. 225.—Appalachian Chain.

fold is really composed of a number of subordinate folds. It is seen that the folds are strong along the crest, but die away in gentle undulations westward until the strata become horizontal.

Rate of Mountain-Formation.—The uprising of a mountain-range is probably in all cases extremely slow, so much so that it may be going on now without our observing it. Hence, though so deeply denuded, it is not necessary to suppose they ever were higher than now. An admirable proof of this slowness is pointed out by Powell in the case of the Uintah Mountains. This range consists of a single great fold of stratified rocks, which has risen right athwart the course of the Green River. But so slow has been the uprising, that the river has not been turned from its course, but has cut through the range to the bottom (Fig. 218). *The uprising has not been faster than the down-cutting of the river.*

Thickness of Mountain-Sediments.—Mountain-chains seem always to be composed of sedimentary rocks of enormous thickness. The strata composing the Appalachian chain are 40,000 feet thick, while the *same strata* on the Mississippi River are only 4,000 feet. According to Clarence King, the Wahsatch Mountains are composed of 56,000 feet of conformable strata. These thin out eastward, so that the palæozoics, which are 32,000 feet thick in the Wahsatch, become only 1,000

feet on the plains.[1] According to Powell, the strata exposed on the flanks of the Uintah Range are 32,000 feet thick. According to Whitney, the cretaceous strata alone of the Coast Range are 20,000 feet thick. We have taken these examples from the United States, but the same is true everywhere. The strata of the Alps, for example, are 50,000 feet thick.[2] It seems certain that the origin of mountain-chains is in some way connected with thickness of sediments; that mountain-chains are, in fact, formed by the crushing together and folding of lines of thick sediments.

Foldings and Metamorphism.—In consequence of the foldings, we find associated with mountains fissures, dikes, veins, etc. If any liquid matters existed beneath, these would naturally be squeezed out through the fissures, and hence we find outpourings of lava associated with mountain-chains. In consequence of the thickness of the sediments, and also from the heat developed by crushing, mountain-strata, especially those along the crest, which are the lowest, are usually metamorphic (p. 224). In fact, thickness, folding, and metamorphism, not only go together, but seem to be proportional to each other. Thus, as already stated, the Appalachian strata, which in the Appalachian region are 40,000 feet thick, gradually thin out westward until they become only 4,000 on the Mississippi River. Both the foldings and the metamorphism diminish and pass away in the same direction.

Inspection of the figures given above (Figs. 221 and 224) shows—1. That mountain-*chains* are necessarily *anticlinal.* This, however, is far from being true for *ridges;* which, we will show hereafter, are often *synclinal.* 2. It shows that the rocks of mountain-crests are usually *granitic* or *metamorphic.* 3. That the rocks of the crest are usually lower in the geologic series, i. e., older than the flanking strata, these lower rocks of the crest having been exposed by enormous erosion. Therefore mountain-regions have been the great theatres—1. Of sedimentation before the mountain was formed; 2. Of *upheaval* in the formation of the chain; and, 3. Of erosion which determined the present outline. Add to these the *metamorphism*, the *fissures*, *slips*, *dikes*, *veins*, and *volcanic outbursts*, and it is seen that all geological agencies concentrate there.

Mountain-Sculpture.

All mountain-*chains* have been formed in the same general way, viz., by a bulging of the earth's crust along certain lines, produced by interior contraction. But the original mountain-plateau thus formed has been in all cases subsequently so enormously sculptured by aqueous agencies as to obscure the origin of the chain and confuse the use of the term *mountain.* This term is loosely used to express every conspicuous inequality of surface, whatever be its origin, from a great chain, like the Andes or Himalayas, to isolated erosion hills of a few

[1] King, "The Survey of the Fortieth Parallel," vol. i., p. 122.

[2] *Archives des Sciences*, vol v., p. 127, 1881.

hundred feet altitude. But we should carefully distinguish mountain-*chains* from hills, ridges, peaks, formed by erosion. The one belongs to *mountain-formation*, the other to *mountain-sculpture*. The *grand forms*, the chain always, the ranges usually, are produced by *interior* or igneous agencies, and have only been modified by exterior or aque-

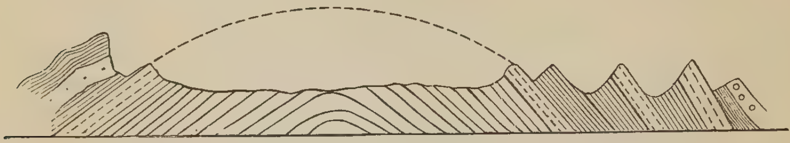


FIG. 226.—Section across the Valley of East Tennessee (after Safford).

ous agencies; but in some cases even what are called ranges, with their wide intervening valleys, have been produced by erosion. The valley of East Tennessee, fifty miles wide, separating the Cumberland from the Blue Range, has been formed by this cause. Fig. 226 is a section across a portion of the valley of East Tennessee, the length of the section being about twenty miles. It is evident that it has been swept out by erosion alone. On account of the immense work which has in all cases been done by erosion, and the grand forms which have often resulted, many writers divide mountains into two classes, viz., mountains of *up-heaval* and mountains of *denudation*. It is better, however, to treat the subject of mountains under two heads, viz., mountain-*formation* and mountain-*sculpture*.

Resulting Forms.—It is very interesting to trace the laws of form resulting from erosion. These laws have been brought out chiefly by Lesley.[1] We have added some from our own observations:

1. *Horizontal Strata.*—Horizontal or very slightly undulating strata give rise by erosion to flat-topped ridges or table-mountains.

FIG. 227.

Fig. 227 is an ideal section of such table-mountains. The outcrop of harder strata on the slope will often determine benches. This table-

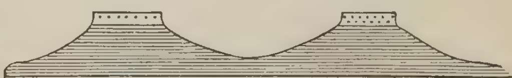


FIG. 228.—Table-Mountains.

form is especially conspicuous if the eroded table-land is capped by hard sandstone, or by lava, as in Fig. 228. Examples of this kind of

[1] "Manual of Coal."

erosion hills are found abundantly in Illinois, Iowa, Tennessee, and in Arizona. We give in Fig. 229 an actual section across Cumberland

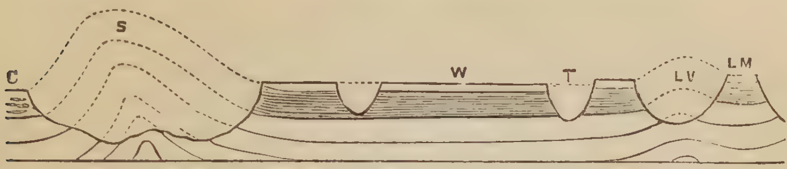


FIG. 229.—Section across Cumberland Plateau and Lookout Mountain, Tennessee.

table (*C*), Sequatchee Valley (*S*), Walden's Ridge (*W*), Tennessee River (*T*), Lookout Mountain Valley (*LV*), and Lookout Mountain (*LM*), Tennessee, in which this structure is well seen.

On the other hand, if the strata be very soft, then erosion produces steep, rounded hills, standing thickly together like potato-hills on a

FIG. 230.—Bad Lands, north of Uintah Mountains (after Powell).

large scale, or, when somewhat firmer, like crowded pinnacles (Figs. 230 and 231). The singular aspect of the *Bad Lands*, or soft tertiary lake-deposits of the Rocky Mountain region and of Oregon, is thus produced.

The forms represented by Figs. 228 and 229 graduate insensibly into the next, viz.:

2. *Gently-folded Strata.*—These by erosion usually produce *synclinal* ridges and anticlinal valleys. This is beautifully shown in the

subjoined section of the Appalachian coal-fields in Pennsylvania. By restoring the strata as in the figure, it is seen that the original ridges

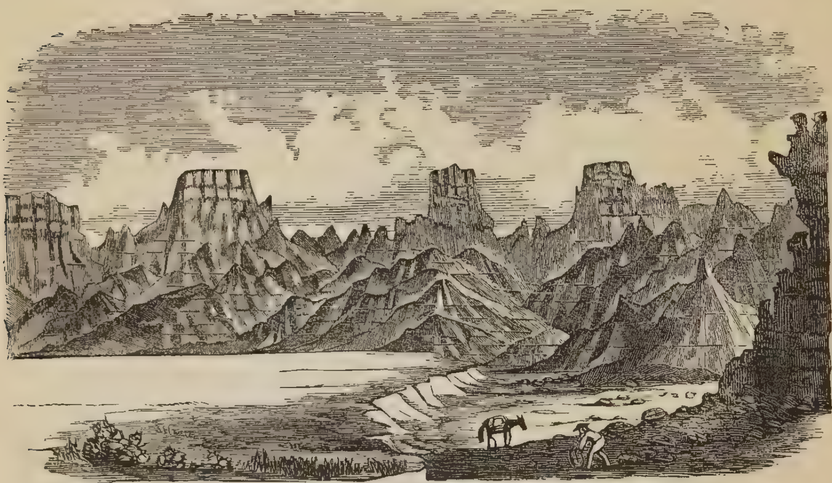


FIG. 231.—Mauvaises Terres. Bad Lands (after Hayden).

have become hollows, and the original hollows have become ridges. The reason of this seems to be that the bending of the strata in oppo-

FIG. 232.—Section of Coal-Field of Pennsylvania (after Lesley).

site directions crushes together and *hardens* them in the synclinals, and stretches them and perhaps breaks them along the anticlinals. Thus the erosion has taken effect on the anticlinals more than the synclinals.

3. *Strongly-folded or Highly-inclined Outcropping Strata.*—In these the ridges and valleys are determined by the outcrop of harder and

FIG. 233.—Parallel Ridges.

softer strata respectively. In the ideal section Fig. 233 the ridges are determined by the outcrop of a succession of hard sandstone strata which resisted erosion more than the intervening soft shale, *sh*. Beau-

tiful examples of ridges and valleys formed in this way are found in the Appalachian chain, especially in Virginia. Standing on the top of Warm Springs Mountain, a dozen or more parallel ridges may be counted, each with a longer slope on one side, and a steeper slope on the other, like billows ready to break. The crest of each ridge is determined by an outcropping sandstone, and the valleys by the softness of the intervening shales. Fig. 226, on p. 256, shows the formation of ridges in this way in Tennessee. A similar structure on a magnificent scale is seen in the hog-backs of the Uintah Mountains described by Powell. In Fig. 233 I have represented a *single* series of strata containing *several* sandstones; but sometimes by repeated foldings the

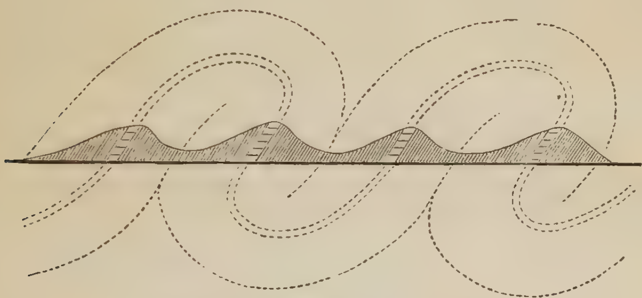


FIG. 234.—Parallel Ridges in folded Strata.

same sandstone or other hard strata may form *many* ridges. This is shown in Fig. 234.

In ridges determined by the outcrop of hard strata the relative slope on the two sides is determined by the dip of the strata. If the strata are perpendicular, the slopes on the two sides are equal (Fig. 235,

FIG. 235.

a); but if the strata are inclined, the longer slope is on the side toward which the strata dip, and the difference of the slopes increases as the angle of dip is less (Fig. 235, *b* and *c*). This case passes by insensible gradations into the next, viz.:

4. *Gently-inclined Outcropping Strata.*—These by erosion, perhaps under peculiar climatic conditions, give rise to a sucession of broad,

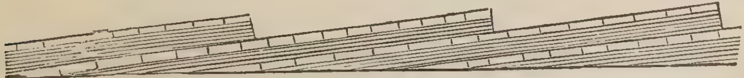


FIG. 236.

nearly level tables, coincident with the face of a hard stratum, terminated by parallel lines of cliffs. Fig. 236 is an ideal section of such

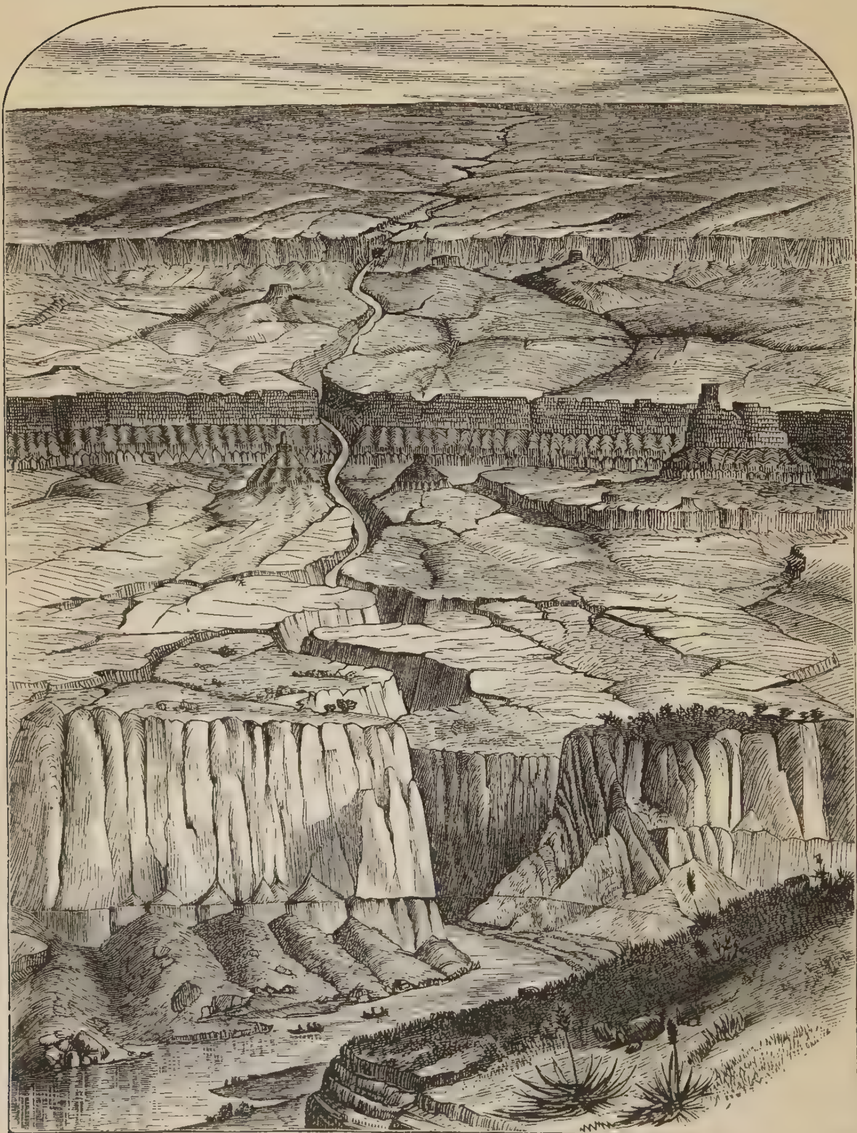


FIG 237.—Bird's-eye View of the Terrace Cañon (after Powell).

strata. This form of sculpture is developed on a magnificent scale in the region of Colorado Plateau. Fig. 237, taken from Powell, shows

three such tables, twenty to sixty miles wide, terminated by as many cliffs, 1,200 to 2,000 feet high. It is evident that the drainage of the region would be against the foot of the cliffs, and that, therefore, all the cliffs recede by erosion.

5. *Highly-metamorphic or Granitic Rocks.*—In granitic or highly-metamorphic regions, where the stratification is indistinct or wanting, the ridges and peaks can generally be traced to the relative hardness of lines or spots, or else to some *peculiar rock-structure.* Thus the *domes* and *spires* so conspicuous about Yosemite have evidently been determined, the one by a concentric structure on a huge scale, the other by a coarse, perpendicular cleavage. In all cases erosion-inequalities, once commenced, tend to increase by the concentration of erosion in the valleys first formed.

The Age of Mountain-Chains.—The *time* of formation of a chain or a range is determined by the age of the strata which enter into its structure, or which lie inclined on its flanks. Thus, the mountain represented in Fig. 221 (p. 252) must be younger than the *tilted* strata (a) on its flanks; for the strata must have been first deposited in an horizontal position, and afterward tilted, when the mountain was formed; but it must be older than the *horizontal* strata (b), for these are yet undisturbed. When mountain-chains have been gradually raised by *successive* upheavals, this fact, and the date of the successive upheavals, are known by the existence and the age of the several series of tilted or folded strata, unconformable with each other. Thus, in Fig. 222 (p. 252), the chain was raised first between the periods of deposition of a and b, and again higher, between the periods of deposition of b and c. Thus, it is known that the Appalachian was formed at the end of the Palæozoic era; for all the Palæozoic strata enter into its folded structure, while even the oldest Mesozoic strata do not. By similar means, it is ascertained that the Sierra Range was formed at the end of the *Jurassic*, while the Coast Range was not formed until the end of the *Miocene.*

It seems most generally true that the *oldest* chains are only of *moderate altitude*, while the highest mountains are among the youngest. The converse of these propositions, however, is by no means true, for there are many young mountains which are also of moderate altitude. In the United States, the Laurentides are the oldest, then the Appalachians, and then the Sierra Nevada. In South America, the Brazilian mountains are older than the higher Andes. In Europe, the Ural Mountains and the Scandinavian mountains are older than the loftier Alps. The Himalayas, also, are among the youngest of mountains, at least in their last development. This may be due in part to the enormous erosion of the older chains, and in part to other causes, yet imperfectly understood.

Theory of the Origin of Mountain-Chains.[1]

We have already (p. 78, *et seq.*) given reasons for believing that the usual view that the earth is an incandescent liquid globe, covered by a solid shell twenty-five to fifty miles thick, is untenable, and therefore that geological theories must be reconstructed on the basis of a substantially solid earth. We have also shown (p. 168) how continents and sea-bottoms are probably formed by the unequal radial contraction of a solid earth. We wish now to show how mountain-chains also may be formed on this supposition.

A cooling, solid earth may be regarded as composed of concentric isothermal shells, each cooling by conduction to the next outer, and the outermost by radiation into space. Furthermore, under these conditions, at first and for a long time, the outermost shell would cool the fastest; but there would eventually come a time when, the surface having become substantially cool, and moreover receiving heat from external sources (sun and space) as well as internal, its temperature would become *nearly fixed*, while the interior would *still* continue to cool by conduction. This has probably been the case during the whole *recorded* history of the earth. The interior, now cooling faster, *would also contract faster, than the exterior.* There is another cause which would contribute to the same result: The amount of contraction for *equal* cooling, or the coefficient of contraction, is greater at high than at low temperatures; and therefore for equal, or even slightly less, loss of heat, the hot interior would contract more than the cool exterior. Now, therefore, the interior, for both of these reasons, contracting more rapidly than the exterior, the latter, following down the shrinking interior, would be subjected to powerful *horizontal pressure*, which continuing to increase with the progressive interior contraction, the exterior must eventually *yield* somewhere. *Mountain-chains are the lines along which the yielding of the surface to horizontal thrust has taken place.* But, observe: According to our view, this yielding is not by upbending into an arch, leaving a hollow space beneath, nor yet into such an arch, filled and supported by an interior liquid, as usually supposed; but *by mashing or crushing together horizontally, like dough or plastic clay, with foldings of the strata and an upswelling and thickening of the whole squeezed mass.*

The proofs of this proposition are found in the structure of mountains, and are mainly of two kinds, viz., *folded strata* and *slaty cleavage.*

Folded Strata.—The complex foldings so universal in mountain-

[1] This subject is certainly best taken up here, but some very general knowledge of Part III. is necessary to its full appreciation. Those who have not this general knowledge had perhaps better put it off to the end of the course.

ranges cannot be accounted for except by horizontal crushing. Simple inspection of the structure of such ranges as the Coast Range of California or the Appalachian (Figs. 220 and 225) is sufficient to convince one of this. But horizontal crushing must produce corresponding *vertical upswelling*. It only remains, therefore, to show that the amount of the upswelling thus produced is sufficient to account for the greatest ranges. In the Coast Range there are at least five anticlines alternating with as many synclines, closely appressed.[1] In the Alps, according to Renevier,[2] there are at least seven closely-appressed folds. In the Appalachian the folding is certainly not less. In most great mountain-ranges it is probable that in the act of mountain-formation the sediments were crushed into one-third of their original horizontal extent, and therefore the crushed mass was swollen to three times its original thickness. When we remember the great thickness of sediments, it is evident that we need not seek further for the cause of the elevation of mountains.

Slaty Cleavage.—But the horizontal crushing and the vertical upswelling are demonstrated also by the phenomenon of slaty cleavage.

We have already seen (p. 181, *et seq.*) that slaty cleavage is certainly produced by powerful pressure perpendicular to the cleavage-planes, by which the whole rock-mass in which it occurs has been mashed together and shortened in that direction, and correspondingly extended in the direction of these planes; furthermore, as the planes are nearly or quite vertical, that the rock-mass has been crushed together horizontally and *swollen up vertically*. As a necessary consequence of the crushing together, we find associated the most complex *foldings*, not only of the strata, but also of the layers, and even of the finest lines of lamination. Thus, *plication is always associated with cleavage;* and, *vice versa*, cleavage, when the rock-material is suitable for developing this structure, is always associated with plication; and both are associated with mountain-chains.

A mashing together horizontally and an extension vertically are therefore certain in slaty cleavage, and in mountain-chains where slaty cleavage occurs. It only remains, therefore, to show that *the amount of upswelling*, absolutely proved by this method also, *is fully adequate to account for the upheaval of the greatest mountain-chains.*

We have seen (p. 182) that, taking any ideal cube or sphere of the original unsqueezed mass, in the process of mashing, the diameter at right angles to cleavage (horizontal and in the direction of pressure) has been diminished, that in the dip of the cleavage (vertical) has been increased, while that in the strike of the cleavage is unaffected. Now, it

[1] *American Journal of Science*, vol. ii., p. 297, 1876.

[2] *Archives des Sciences*, vol. lix., p. 5, 1877.

has been shown that in the case of the first two diameters mentioned, viz., the horizontal in the direction of pressure and the vertical, their original equality has been changed into a ratio of 2 : 1, 4 : 1, 6 : 1, 9 : 1, and in some cases even 11 : 1 ; the average being 5 or 6 : 1. It follows, therefore, that the *change of each* diameter, either in the direction of compression or of elongation, must be the *square roots* of the above ratios. Thus, if a cube of three inches' diameter be crushed together horizontally and allowed to extend only vertically, until these previously equal diameters become as 9 : 1, it is evident that the horizontal diameter has been diminished and the vertical diameter increased, each three times. Taking 6 : 1 as the ratio, in cleaved slates, of diameters originally equal, we may assert that in cleaved rocks *the whole mass has been swollen up two and a half* (2.45) *times its original thickness.* Suppose, then, a mass of sediments 10,000 feet thick subjected to horizontal pressure and crushing sufficient to develop well-marked cleavage-structure : *a breadth of two and a half miles has been crushed into one mile, and the* 10,000 *feet thickness swollen to* 25,000 *feet, making an actual elevation of the surface of* 15,000 *feet.* Now, we actually have strata, not only 10,000, but 20,000, and even 40,000, feet thick.

We are justified, therefore, in asserting that *the phenomena of plication and of slaty cleavage demonstrate a crushing together* horizontally and an upswelling of the whole mass of mountain-sediments ; *that the amount of upswelling produced by this cause alone is sufficient to account for the elevation of the greatest mountain-chains.* No other theory of mountain-formation takes cognizance of slaty cleavage. Some take cognizance of the crushing and folding, but in all it is a *subordinate accompaniment,* instead of a sufficient *cause,* of the elevation.

Experimental Proof.—Finally, the folded structure of mountains has been produced by Favre and Daubrée by actual experiment.[1]

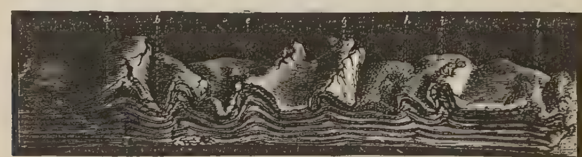


FIG. 237a.—Layers of Clay folded by Lateral Pressure (after Favre).

Plastic masses, consisting of variously-colored layers of clay or wax, were pressed together horizontally so that the layers were crumpled, and the mass thickened. Many of the phenomena of mountain-struct-

[1] *Archives des Sciences*, vol. lxii., p. 193, 1878, and *Comptes Rendus*, vol. lxxxvi., pp. 734, 864, 928.

ure were thus completely reproduced. Fig. 237, *A*, represents the result of such an experiment.

Unquestionably, therefore, mountain-chains are produced by horizontal pressure crushing together the whole rock-mass and swelling it up vertically, the horizontal pressure being the necessary result of the secular contraction of the interior of the earth. It is possible that even *continents* may have been formed by a similar yielding to horizontal thrust, and a similar crushing together and upswelling. If so, it is necessary to suppose that the amount of horizontal crushing is much less, but the depth affected much greater, than in the case of mountain chains. But, as we find no unmistakable relation between elevation and amount of crushing, except in the case of mountain-chains, we have preferred to attribute the formation of continents and sea-bottoms to *unequal radial* contraction (p. 168).

Let us now apply this theory to the explanation of the most conspicuous phenomena associated with mountain-chains.

1. **Thick Sediments of Mountain-Chains.**—It is now generally acknowledged that mountain-chains consist either wholly or principally of enormously thick sediments crumpled together. But where do such great accumulations of sediments now take place? Evidently off the shores of continents and in inland seas. Nearly the whole *débris* of eroded land is deposited near shore—only a very small quantity of very fine sediment reaching deep-sea bottom. Hence great accumulations take place only along shore. Mountain-chains, therefore, are evidently formed by the crushing together and upswelling of sea-bottoms where great accumulations of sediments have taken place; and, as such accumulations usually occur off the shores of continents, *mountain-chains are formed by the up-pressing of marginal sea-bottoms.* The proof of this proposition is found in the history of the chains of the North American Continent.

(*a.*) **Appalachian Chain.**—The area now occupied by this chain was, during the whole Silurian and Devonian ages, the *eastern margin of the bed of the great interior Palæozoic Sea,* which then covered nearly the whole basin now drained by the Mississippi River. During all this time the whole of this interior sea, but especially its eastern margin, received sediments from a continental mass northward (the Laurentian area), and also especially *from a continental mass to the eastward.* Besides the marks of shore-deposit, found abundantly in the Appalachian strata, other evidences are daily accumulating that the area to the east of the Appalachian chain—the so-called primary or gneissic region of the Atlantic slope—is largely Laurentian, and therefore was *land* during the Palæozoic era. The size of this old eastern continental mass it is now impossible for us to know, since it has been partly covered by later deposits, and is perhaps even partly covered

now by the sea ; but, judging by the enormous quantity of sediments, 30,000 feet thick, carried westward from it into the Palæozoic interior sea, and deposited along the eastern margin of this sea, it must have been very large.

At the end of the Devonian age much of the middle portion of the interior Palæozoic Sea was upheaved and became land ; and the Appalachian region became now alternately a coal-marsh, a lake, and an inland sea or estuary, emptying into the ocean southward (*see* map, page 289—the eastern black area). Into this estuary, or marsh, during the Coal period, sediments were brought down from land north, east, and west, until 10,000 feet more were deposited. During the whole of this immense time (Palæozoic era), while the 40,000 feet of sediments were depositing, this area—whether sea-margin bottom, or *estuary-bottom*, or *coal-marsh*—slowly subsided, so as to maintain nearly the same level. This is certain for the Coal period (for every coal-seam indicates a marsh nearly at sea-level), and almost equally certain for the previous periods, for marks of shallow-water shore-deposits are found throughout. Besides, it seems to be a general law throughout the whole history of the earth that areas of great sedimentation have been areas of slow subsidence *pari passu.* The same seems to be true now. Nearly all great river-deltas are slowly subsiding (p. 129). In fact, in all shallow-water deposits, and therefore in all shore-deposits, the accumulation would soon cease, and therefore would never become thick, *but for subsidence, which constantly renews the conditions of deposit.* The subsidence of the Appalachian area, therefore, must have been 40,000 feet vertical.

Observe, then, that during the whole Coal period the Appalachian region, so far from being a mountain-chain, was a northeast and southwest *trough*, lower than the land to the east and west of it. At the end of the Coal period occurred the *Appalachian revolution. The great mass of sediments which had been accumulating for so many ages, yielded to the horizontal pressure, was crushed together and folded, and swollen upward to a height proportioned to the horizontal crushing.* Thus was formed the Appalachian chain. The mode and the date of its formation are both recorded in its structure. Subsequent sculpturing has made it what it now is. It is probable that in the process of up-pushing of the Appalachian (or possibly at a later time), the eastern continental mass was diminished both in height and in extent on its eastern border, by subsidence.

(*b.*) Sierras.—There can be no doubt that a considerable portion of the area now occupied by the Rocky Mountains (the Basin Range region) was land during the Palæozoic era. The extent and height of this land we do not know. We shall say nothing of the mode of formation of this the oldest portion of the North American Cordilleras, as the his-

tory of its formation is little known. We will commence with a considerable body of land which certainly existed in this region from early Palæozoic times. Now, during the whole Palæozoic era, the *region now occupied by the Sierra range was a marginal sea-bottom receiving abundant sediments from a continental mass to the east.* During the Triassic and Jurassic periods this region was farther away from shore, but still near enough to receive abundant sediment. At the end of the Jurassic this line of enormously thick off-shore deposits, *yielding to the horizontal thrust, was crushed together and swollen up into the Sierra range.* All the ridges, peaks, and cañons—all that constitutes the grand scenery of these mountains—are the result of an almost inconceivable subsequent erosion.

(*c.*) **Coast Range.**—The up-squeezing of the Sierras, of course, transferred the coast-line farther westward, and the region now occupied by the Coast Range became the marginal sea-bottom. This in its turn received abundant sediments from the now greatly-enlarged continent, until the end of the Miocene, and then it also yielded in a similar manner, and formed the Coast Range.

(*d.*) **Wahsatch.**—As the Sierra region was the marginal sea-bottom of the *Pacific* Ocean bordering the *western* coast of the old Basin-region continent, so the Wahsatch Range was the marginal sea-bottom of the great interior sea (Fig. 728) bordering on the eastern coast of the same continent. The *débris* of this continent accumulated as off-shore sediments on both coasts. The western sediments yielded at the end of the Jurassic, and the Sierra was formed; the eastern sediments yielded at the end of the Cretaceous, and the Wahsatch was formed.

(*e.*) **Alps.**—Mr. Judd has recently shown that the region of the Alps, during the whole Mesozoic and early Tertiary, was a marginal sea-bottom (probably a mediterranean), receiving sediments until a thickness was attained not less than that of the Appalachian strata. At the end of the Eocene these enormously thick sediments were crushed together with complicated foldings, and swollen upward to form these mountains, and subsequently sculptured to their present forms.[1]

Thus, then, it is quite certain that the places now occupied by mountain-chains have been, previous to their formation, places of great sedimentary deposit, and therefore most usually marginal sea-bottoms. In some cases, however, perhaps in many cases, *the deposits in interior seas or mediterraneans may have yielded in a similar manner, giving rise to more irregular chains or groups of mountains.*

2. Position of Mountain-Chains along the Borders of Continents.—The view that mountain-chains are the up-squeezed sediments of mar-

[1] *Geological Magazine*, 1876, vol. iii., p. 337.

ginal sea-bottoms completely explains the well-known law of continental form, viz., *that continents consist of interior basins, with coast-chain rims.* In fact, the theory necessitates this as a *general* form of continents, but at the same time prepares us for exceptions in the case of mountains formed from mediterranean sediments.

3. **Parallel Ranges.**—Whitney has drawn attention [1] to the fact that "parallel ranges of the same system are *formed successively*," and we would add, most usually formed successively *coastward.* An example is found in the North American Cordilleras, the three parallel ranges of which were successively formed—first the Rocky Mountains, then the Sierras, and last the Coast chain. The same is probably true of many other mountains. Both the general parallelism and the *successive* formation, and the successive formation *coastward*, are explained by the theory.

4. **Metamorphism of Mountain-Chains.**—Admitting, then, as quite certain, that mountains are formed by the squeezing together and the upswelling of lines of off-shore sediments, the question still occurs, "*Why does the yielding to horizontal pressure take place along these lines in preference to any others?*" The answer to this question is found in the metamorphic changes and *the aqueo-igneous softening of deeply-buried sediments.* Taking the increase of heat as we descend into the interior of the earth to be 1° for every 50 feet, and adding the mean surface temperature, 60°, the lower portion of 10,000 feet of strata must have a temperature of about 260°, and of 40,000 feet of strata 860° Fahr. Even the former moderate temperature, long continued in the presence of the included water of sediments, would probably produce incipient change, especially if the included waters be at all alkaline. The latter temperature, we know from Daubrée's experiments, would certainly produce aqueo-igneous pastiness or even aqueo-igneous fusion. Now, this aqueo-igneous softening would affect not only the sediments, *but also the crust beneath on which the sediments were deposited.* Thus would be produced a *line of weakness, and therefore a line of yielding to the horizontal crushing.* Thus we fully account for the formation of the chain along the line of thick sediments, and at the same time for the metamorphism of the strata, especially the lower strata, involved in mountain-structure. By this view, of course, the exposure of metamorphic rocks on the surface, as already stated (p. 217), is the result of erosion. Even the granite axis, in most if not in all cases, is but the lowermost, and therefore the most changed, portion of the squeezed mass exposed by erosion; although it is possible that in some cases the granite may have been *squeezed out* as a pasty mass through a rupture at the top of the swelling mass of strata.

Thus it will be seen that the *thickness* of mountain-strata, the nor-

[1] Whitney on "Mountain-Building."

mal *position of chains* on the borders of continents, the *successive formation coastward* of parallel ranges, and the *metamorphism* of the strata of great chains, are all accounted for, and shown to be necessarily connected with each other.

5. **Fissures and Slips, and Earthquakes.**—The enormous foldings of strata which must always occur in the formation of a mountain-chain by lateral thrust would of necessity often produce fractures at right angles to the thrust, or parallel to the folds, i. e., to the range. The walls of such fissures would often slip *by readjustment* by the force of gravity, or else, in cases of great mashing together, *might be pushed one over the other by the sheer force of the horizontal thrust.* The former case would give rise to those slips in which the hanging wall has dropped down, which are by far the most common slips in gently-folded strata (Figs. 204, 205, pp. 233, 234). The latter would give rise to those cases often found in strongly-folded strata, as in the Appalachian (Fig. 199, p. 230), in which the hanging wall has been pushed upward, and slidden over the foot-wall. The *sudden rupture* of the earth's crust under accumulating horizontal forces, or the sudden slipping of the broken strata, sufficiently accounts for the phenomena of earthquakes.

6. **Fissure-Eruptions.**—It will be observed that, according to our view, beneath every thick mass of sediments there is a layer of aqueo-igneously softened matter. This it is which determines the line of yielding, and therefore the place of the mountain-chain. Perhaps this aqueo-igneous softening may be sufficient to account for some cases of semi-fused lavas and hot volcanic muds; although the intense heat of ordinary fused lavas cannot be thus accounted for. But as soon as the yielding commences, *mechanical energy*, by means of the friction of the crushed strata, *is converted into heat.* Mr. Mallet believes[1] that the heat thus produced is sufficient to fuse the rocks. Beneath every chain, therefore, there must be, or has been, *a mass of fused matter.* Now, in the progressive crushing together of the mountain-strata, it follows inevitably that this fused matter is squeezed *into* fissures of the folded strata, forming dikes, or *squeezed out* through such fissures, and outpoured upon the surface as *great sheets of lava.* Thus the association of these lava-floods with mountain-chains is also completely accounted for; and it is simply impossible to account for them in any other way, unless, indeed, by Fisher's view of superheated steam issuing from the fissures.

7. **Volcanoes.**—No doubt the study of causes now in operation forms the only true foundation of a scientific geology. Nevertheless, the assimilation of agencies in previous geological epochs to those now in operation may be carried too far. For instance, there is a strong tendency among the best geologists to make volcanoes or crater-eruptions

[1] "Philosophical Transactions" for 1872.

(the only form of eruption now going on) the type of all igneous eruptions in all times. But the attentive study of the mode of occurrence of eruptive rocks will show that by far the larger quantity have come through fissures, as explained above, and not through craters. No one who has examined the eruptive rocks of the Pacific coast can for a moment believe that these immense floods of lava have issued from craters. The lava-flood of the Sierra and Cascade ranges is certainly among the most extraordinary in the world. Commencing in Middle California as separate lava-*streams* (which, however, cannot be traced in any case to craters), in Northern California it becomes an almost continuous *sheet*, several hundred feet thick; and in Oregon an overwhelming *flood*, at least 2,000 feet thick. In apparently undiminished thickness it then stretches through Washington Territory and far into British Columbia. An area 800 miles long and 100 miles wide is apparently entirely covered with a universal lava-flood, which, in the thickest part, where it is cut through by the Columbia River, is certainly not less than 3,000 feet thick. Over this enormous area there are scattered about a dozen extinct volcanoes—mere pimples on its face. It is incredible that all this flood should have issued from these craters. There is no proportion between the cause and the effect. We therefore unhesitatingly adopt the view of Richthofen,[1] that these immense floods of lava, so often associated with mountain-chains, and often forming, as in this case, the great mass of the chain itself, have issued, not from *craters*, but from *fissures;* and that volcanoes or crater-eruptions are secondary phenomena, arising from the access of water to the hot interior portions of great fissure-eruptions. Thus, as monticules are parasites on volcanoes, so are volcanoes parasites on fissure-eruptions, and fissure-eruptions themselves parasites on an interior fluid mass. This interior fluid mass, however, according to Richthofen, is the supposed *universal liquid interior;* while, according to our view, it is *the sub-mountain reservoir*, *locally formed*, as above explained.

By this theory it is necessary to suppose that there have been, in the history of the earth, *periods of comparative quiet*, during which the forces of change were gathering strength; and *periods of revolutionary change*—periods of gradually-increasing horizontal pressure, and periods of yielding and consequent mountain-formation. These latter would also be periods of great fissure-eruptions, and would be followed during the period of comparative quiet by volcanoes gradually decreasing in activity. The last of these great fissure-eruption periods in the United States occurred in the later Tertiary. Since then we have been in a crater-eruption period, which has been steadily decreasing in activity, until only geysers and hot springs remain to tell us of the still hot interior masses of the great fissure-erupted lavas. The periods of

[1] "Natural History of Volcanic Rocks," Memoirs of California Academy of Science.

revolution separate the great eras and ages of geological history, and are marked by *unconformity, because the sea-margin sediments*, upon which the sediments of the next period are necessarily deposited, are *crumpled up;* and also by change of species, because changes of physical geography determine changes of climate, and therefore enforced migration of species.

The theory here presented accounts for all the principal facts associated in mountain-chains. This is the true test of its general truth. It explains satisfactorily the following facts: 1. The most usual position of mountain-chains on the borders of continents. 2. When there are several ranges belonging to one system, these have been formed successively coastward. 3. Mountain-chains are masses of immensely thick sediments. 4. The strata of which mountain-chains are composed, are strongly folded, and, where the materials are suitable, are affected with slaty cleavage; both the folds and the cleavage being usually parallel to the chain. 5. The strata of mountain-chains are usually affected with metamorphism, which is great in proportion to the height of the chain and the complexity of the foldings. 6. Great fissure-eruptions and volcanoes are usually associated with mountain-chains. 7. Many other minor phenomena, such as fissures, slips, and earthquakes, it equally accounts for.

Rev. O. Fisher and Captain Dutton[1] have objected to the above view, that at the calculable rate at which the earth is now cooling, the amount of contraction is wholly inadequate to produce the supposed effect. But even if this be true, the objection does not touch the *fact* of contraction, which is certain, but only the *cause* of contraction, viz., by cooling. Other causes of contraction are conceivable, for example, loss of interior vapors and gases, according to Fisher's theory of volcanoes (p. 93).

CHAPTER VI.

DENUDATION, OR GENERAL EROSION.

The term *denudation* is used by geologists to express the general erosion which the earth-surface has suffered in geological times. The correlative of denudation is *sedimentation*, and the amount of denudation is measured by the amount of *stratified rocks.*

Agents of Denudation.—The agents of erosion, as we have already seen in Part I., are: 1. *Rivers*, including under this head the whole course of rainfall on its way back to the ocean whence it came;

[1] Fisher, "Cambridge Philosophical Transactions," vol. xii.; Dutton, *Penn Monthly*, May and June, 1876.

2. *Glaciers*, including under this head not only glaciers proper, but moving *ice-sheets*, such as now exist in polar regions and in the Glacial epoch extended far into now temperate regions, and also moving snow-fields, for it is probable that all extensive snow-fields and snow-caps are in motion; 3. *Waves* and *tides;* and, possibly, 4. *Oceanic currents.*

Oceanic currents usually run on a *bed* and between *banks* of still water, and therefore produce no erosion. It is possible, however, that a rising sea-bottom may be eroded by this agent; but as we have no knowledge of such effects, we are compelled to omit this from our estimate of the probable rate of denudation. The action of *waves and tides* is violent and conspicuous; yet these agents are so entirely confined to the shore-line that their aggregate effect is but a small fraction of the whole erosion. Prof. Phillips has shown [1] that, taking the coast-lines of the world as 100,000 miles, and making the extravagant estimate that the average erosion along this whole line is equal to that of the English coast, or one foot per annum of a cliff one hundred feet high, still the aggregate wave-erosion is far less than river-erosion, being equivalent to a general land-surface erosion of only $\frac{1}{2000}$ of an inch per annum, or $\frac{1}{12}$ of that which is now going on over the hydrographical basin of the Ganges, and $\frac{1}{6}$ of that going on in the basin of the Mississippi. *Glaciers* and rivers, therefore, are the great agents of erosion. The one takes the place of the other, according as falling water takes the form of *rain* or *snow;* both come under the general head of circulating meteoric water. In a general estimate of the rate of denudation we may, therefore, without sensible error, regard it as the work of circulating meteoric water.

Again, although it is probable that the erosive power of glaciers is far greater than that of rivers, yet their action is so much more local, both in *time and space*, that we believe we may take the average rate of river-erosion as a fair representative of the average rate of denudation.

Amount of Denudation.—A mere glance at the figures below will show in a general way the manner in which geologists estimate the amount of denudation in certain regions. In almost all countries, especially in mountain-regions, we find slips varying from a few feet to many thousands of feet perpendicular (Fig. 238). There are slips in the Appalachian chain which are estimated to be 8,000, and even one 20,000, feet perpendicular. And yet in most cases the escarpment, which would otherwise exist, is completely cut away, so that no surface-indication of the slip exists. Evidently in such cases there must have been erosion on the elevated side, at least equal to the amount of slip, and probably much greater. The dotted line represents the probable original surface.

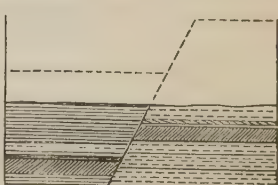


FIG. 238.

[1] "Life, its Origin and Succession," p. 130.

Sometimes the horizontal strata of isolated mountain-peaks corresponding to each other (mountains of erosion) show that these are but scattered fragments of a once high plateau, which has been removed by

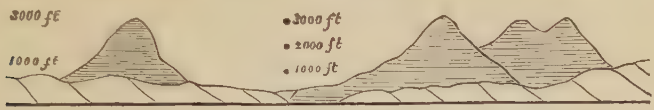


FIG. 239.—Denudation of Red Sandstone, Northwest Coast of Ross-shire, Scotland.

erosion, as shown in the annexed figure (Fig. 239), and in the sections of the Appalachian, on pages 256, 257 (Figs. 226, 229). In such cases the erosion must have been at least equal to the height of the peaks, and

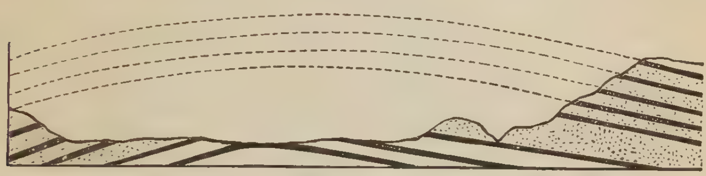


FIG. 240.—Section across Middle Tennessee. The dotted lines show the amount of matter removed.

may have been to any extent greater. The accompanying section across Middle Tennessee shows a vertical erosion of 1,200 to 2,400 feet, over the whole valley of Middle Tennessee, which is sixty miles across,

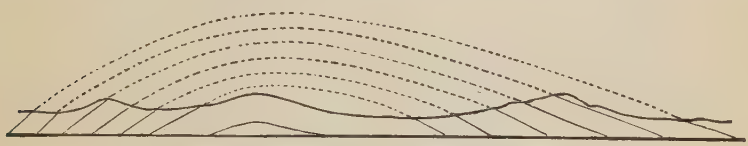


FIG. 241.—Section through Portions of England.

and one hundred miles long. In most cases the removed matter is not so easily estimated as in those mentioned. The strata in mountain-chains are usually folded in a very complex way, and then denuded.

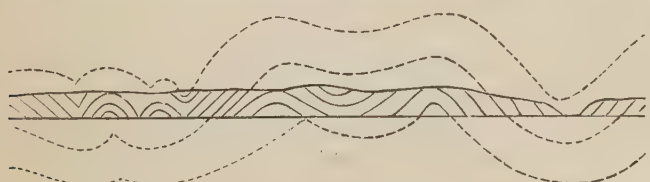


FIG. 242.—Section through Portions of England.

But the ideal restoration of these may be effected, and the amount of erosion approximately estimated. Figs. 241 and 242 are sections across the mountainous parts of England, as restored by Prof. Ramsay.

Average Erosion.—By these methods Prof. Ramsay estimates the denudation over many portions of England to be not less than 10,000 to 11,000 feet in thickness.[1] Over the whole Appalachian region the denudation has probably been enormous, in some places 8,000 to 20,000 feet. Over the whole region of the high Sierra Range, as we have shown,[2] erosion has removed the whole of the Jurassic and Triassic slates, and bitten deep into the underlying granite. The thickness of these slates is not known, but it must be many thousand feet. In the Uintah Mountain region, according to Powell, over an area of 2,000 square miles, an average thickness of three and a half miles

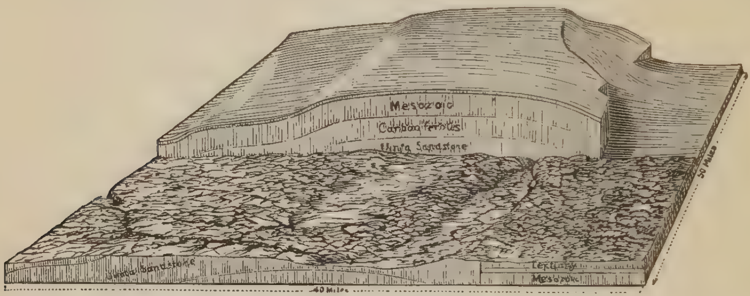


Fig. 243.—Uintah Mountains—Upper Part restored, showing Fault; Lower Part showing the Present Condition as produced by Erosion (after Powell).

has been taken away (Fig. 243), the extreme thickness removed being nearly five miles. From the Wahsatch have been removed 32,000 feet, or six miles thickness of strata (King). Over the whole Colorado Plateau region the succession of cliffs, separated by broad tables (Fig. 237), shows enormous erosion. The average erosion over the whole region has been estimated by Powell and Dutton as 6,500 feet; and the extreme general erosion, not including the cañon-cutting, as 11,000 feet. The whole of this immense mass has been removed, too, since the middle Tertiary.

It seems impossible to avoid the conclusion, therefore, that the *average erosion* over all present land-surfaces has been at least several thousand feet.

There is another mode of estimating the average erosion, viz., by the average thickness of stratified rocks. The *débris* of erosion is carried down into seas and lakes, and forms strata, and the amount of stratified rocks becomes thus the measure of the erosion; the average thickness of sediments, if they had been spread over an equal area, would be an accurate measure of the average thickness removed by erosion. Now, the stratified rocks are in some localities 10,000 feet,

[1] *Geological Observer*, p. 819.

[2] *American Journal of Science and Arts*, vol. v., p. 325.

20,000 feet, and sometimes 40,000 and 50,000 feet thick. They are scarcely ever found less than 2,000 or 3,000 feet. It is certain, therefore, that the average thickness of strata over the whole known surface of the earth is not less than several thousand feet. Let us take it at only 2,000 feet. But the area of sedimentation, the sea-bottom, is now, and has probably always been, at least three times the area of erosion, the land-surface. Thus an average of 2,000 feet of strata would require an average erosion of 6,000 feet.

Estimate of Geological Times.—There are many facts connected with geology, especially the facts of evolution, which cannot be understood without the admission of inconceivable lapse of time. For this reason it is important that the mind should become familiarized with this idea. It will not be out of place, therefore, to make a rough estimate of time based upon the amount of erosion.

We have already seen (p. 11) that, taking the Mississippi as an average river in erosive power (it is probably much more than an average), the rate of continental erosion is *now* about one foot in 5,000 years. At this rate, to remove an average thickness of 6,000 feet would require 30,000,000 years.[1]

Some may object to this estimate, on the ground that geological agencies were *once* much more active than *now*. It is *probable* that this is true of igneous agencies, since these are determined by the *interior heat* of the earth, and this has evidently been decreasing. It is probable also that this is true of the *chemical* agencies of water in disintegrating rocks and forming soils, since chemical effects are also usually increased by heat. But there is good reason to believe that the *mechanical* agencies of water, i. e., its *erosive power*, have been constantly increasing with the course of time, and are greater now than at any previous epoch except the Glacial epoch.

For observe: The erosive power of water is determined entirely by the *rapidity of circulation of air and water*, and this is determined by *the diversity of temperature* in different portions, and this in its

[1] The above estimate takes the *average* thickness of strata, and supposes it spread evenly over the whole sea-bottom. This is strictly admissible only if we suppose, with Lyell, that land and ocean have often changed places, so that every portion of earth-surface has received sediments. But if, as is now most generally believed, the ocean-basins have remained substantially unchanged, and sediments have accumulated almost wholly on their margins, then we must, it is true, make our measuring-rod, i. e., the rate of sedimentation, much greater, but we must also take the sum of the *extreme* thicknesses of strata in different localities, as the thing to be measured. We, therefore, make another estimate, on this basis, following Mr. Wallace. Taking the whole land-surface (erosion-area) at 57,000,000 square miles, and the sedimentation area as thirty miles wide along a coast-line of 100,000 miles (= 3,000,000 square miles), then with an erosion-rate of one foot in 3,000 years instead of 5,000 years, the sedimentation rate would be nineteen feet in the same time, or one foot in 157 years. But the extreme thickness of strata is at least 177,000 feet. This would take 28,000,000 years.—Wallace, "Island Life," p. 210.

turn *by the size of continents and the height of mountains.* Continents and seas are two poles of a circulating apparatus—at one pole is condensation, at the other evaporation. In proportion to condensation are also evaporation and circulation. Now, there is good reason to believe that, amid many oscillations, there has been throughout all geological times a constant increase in the size of continents and the height of mountains. If so, then the circulation of air and water has been becoming swifter and swifter; the life-pulse of our earth has beaten quicker and quicker, and therefore the waste and supply (erosion and sedimentation) have been greater and greater.[1]

We therefore return to our estimate of 30,000,000 years with greater confidence that it is even far within limits of probability. For, 1. We have taken the average thickness of strata at 2,000 feet, while it is probably much more. 2. We have taken the Mississippi as an average river, and therefore the present rate of general erosion as one foot in 5,000 years: it is probably much less. 3. We have taken the rate of erosion in previous epochs as the same as now, while it is probably much less, for two reasons: 1. The land-surface to be eroded was smaller; and, 2. The erosive power of water was less. Taking all these things into consideration, the time necessary to produce the structure which we actually find is enormously increased.

But even this gives us no adequate conception of the time involved in the geological history of the earth. For rocks disintegrated into soils, and deposited as sediments, are again reconsolidated into rocks, lifted into land-surfaces to be again disintegrated into soils, transported and deposited as sediments. And thus the same materials have been worked over and over again, perhaps many times. Thus the history of the earth, *recorded* in stratified rocks, stretches out in apparently endless vista. And still beyond this, beyond the *recorded* history, is the infinite unknown abyss of the *unrecorded.* The domain of Geology is nothing less than (to us) inconceivable or infinite time.

[1] It is possible that the erosive effect of tides in earliest geological times, far greater than now, on account of the greater proximity of the moon, is an element which should not be neglected (*Nature*, vol. xxv., p. 79).

PART III.

HISTORICAL GEOLOGY;

OR,

THE HISTORY OF THE EVOLUTION OF EARTH-STRUCTURE AND OF THE ORGANIC KINGDOM.

CHAPTER I.

GENERAL PRINCIPLES.

THERE are certain laws underlying all development—certain general principles common to all history, whether of the individual, the race, or the earth. We wish to illustrate these general principles in the more unfamiliar field of geology by running a parallel between the history of the earth and other more familiar forms of history.

1. All history is divided into *eras*, *ages*, *periods*, *epochs*, separated from each other more or less trenchantly by great events producing great changes. In written history these are treated, according to their importance, in separate volumes, or separate chapters, sections, etc. So *earth-history* is similarly divided into geological *eras*, *ages*, *periods*, etc.; and these have been recorded by Nature in separate *rock-systems*, *rock-series*, *rock-formations*, and *rock-strata*. In geology these terms, both those referring to divisions of *time* and those referring to divisions of *record*, are unfortunately loosely and interchangeably used. We shall strive to use them as definitely as possible, the *eras* and the corresponding *rock-systems* being the primary divisions, and the others subdivisions in the order mentioned.

2. In all history successive eras, ages, periods, etc., *usually graduate* insensibly into each other, though sometimes the change is more rapid and revolutionary. In individual history childhood usually graduates into youth, and youth into manhood; yet sometimes a remarkable

event determines a more rapid change. In social and political life, too, successive phases of civilization embodying successive dominant principles usually graduate into each other ; yet great events have sometimes determined exceptionally rapid changes in the direction or the rate of movement. So also is it in geological history. The eras, periods, etc., usually shade more or less insensibly into each other ; yet there have been times of comparatively rapid or revolutionary change. In all history there are periods of comparative quiet, during which forces of change are gathering strength, separated by periods of more rapid change, during which the accumulated forces produce conspicuous effects.

3. Ages, periods, etc., in all history, whether individual, political, or geological, are determined by the rise, culmination, and decline of successively higher dominant forces, principles, ideas, functions. Thus, in individual development, we have the culmination, first, of the nutritive functions ; then of the reproductive and muscular functions ; and, last, of the cerebral functions. And in mental development, also, we have the culmination, first, of the *perceptive* faculties, and memory ; then, the imaginative and æsthetic faculties ; and, last, the reflective faculties ; the first gathering and storing material, the second vivifying it, the third using it in productive mason-work of science. In social history, too, the successive culminations of different phases of civilization have been the result of the introduction and culmination of successive dominant principles or ideas—of successive social forces or functions. So has it been in geological history. The great divisions of time, especially what are called *ages*, are characterized by the introduction and culmination of successive dominant classes of organisms, for these are the highest expression of earth-life. Thus, in geology, we have an age of mollusks, an age of fishes, an age of reptiles, in which these were successively the dominant class.

But since (Law 2) successive ages graduate more or less into and overlap each other, we might expect, and do indeed find, that the characteristics of each age commence in the preceding age. Each age is foreshadowed in the previous age. The same is true of all history.

4. In all history, at the close of an age, the characteristic dominant principle or class declines, but does not perish. It only becomes subordinate to the succeeding dominant class or principle. Thus, to illustrate from individual history: in youth, the characteristic faculties of childhood, viz., perception and memory, decline, and become subordinate to the higher faculty of imagination, and this in turn becomes subordinate to the still higher faculty of productive thought ; and thus the whole organism becomes higher and more complex, each stage of development including not only its own characteristic, but also, in a subordinate degree, those of all preceding stages. The same is true of social

history. Each stage of social development absorbs and includes the social principles and forces characteristic of previous stages, but subordinates them to the higher principles which form its own characteristic, and thus the social organism becomes ever higher, more complex, and varied.

So is it also in geologic history. When the dominance of any class declines at the end of an age, the class does not disappear, but remains subordinate to the next succeeding and higher dominant class, and the organic kingdom, as a whole, becomes successively more and more complex and varied. This is graphically represented by the accompanying diagram,

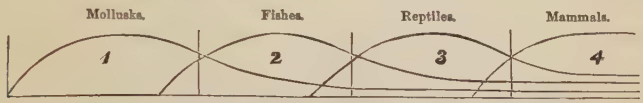


FIG. 244.—Diagram illustrating Successive Culminations of Classes.

in which 1, 2, 3, 4, represent four successive ages determined by the culmination of successive dominant classes.

5. There are two modes of determining and limiting eras, ages, periods, etc., in geology, viz., unconformity of the rock-system and change in the life-system. In written human history, the divisions of time are recorded in separate volumes, chapters, sections, with boards or blanks between. These divisions in the record ought to correspond to conspicuous changes in the character of the most important contents. So, in the history of the earth, the rock-systems, rock-series, rock-formations, are volumes, chapters, sections, respectively, more or less completely separated from each other by unconformity, indicating blanks in the known record; and the most important changes in the contents, i. e., in the life-system, ought to, and usually do, correspond with the unconformity of the rock-system. But if there should be (as there is in some limited localities) a discordance between these two, we should follow the life-system rather than the rock-system, the contents rather than the artificial divisions of the record.

6. As in human history there is a general onward movement of the race, and yet special modifications in character and rate in each country, so in geology there has been a general march of evolution of the whole earth and the organic kingdom, and yet special modifications in character and rate in each continent, and to a less extent in different portions of the same continent. The great eras, ages, and periods, belong to the whole earth alike, and are the same in all countries, but the epochs and the smaller divisions of time, though similar, are probably not contemporaneous in different countries. This fact has probably been too much overlooked by geologists.

Great Divisions and Subdivisions of Time.—Eras.—It is upon these

principles that geologists have established the divisions of *time* and the corresponding divisions of *strata*.

The whole history of the earth is divided into five eras, with corresponding rock-systems. These are: 1. *Archæan* or *Eozoic*[1] era, embodied in the *Laurentian* system; 2. *Palæozoic*[2] era, embodied in the Palæozoic or *Primary* system; 3. *Mesozoic*[3] era, recorded in the *Secondary* system; 4. *Cenozoic*,[4] recorded in the *Tertiary* and *Quaternary* systems; and, 5. The *Psychozoic* era, or *era of Mind*, recorded in the *recent* system.

These grand divisions, with the exception of the last, are founded on an almost universal unconformity of the rock-system, and a very great and apparently sudden change in the life-system, a change affecting not only species but also genera, families, and even orders. Between the *last* and the preceding, it is true, neither the unconformity of the rock-system nor the change in the life-system is so great as in the others; but the introduction of *man* upon the scene is deemed sufficient to make this one of the grand divisions of time.

We have already seen (p. 179) that unconformity is the result of deposit of strata on old eroded land-surfaces, and that it therefore always indicates an *oscillation* of the crust, and an emergence and submergence of land. In every such case, as already explained, a portion of the record is lost, which may or may not be recovered elsewhere. It is certain that if the lost leaves could be all recovered, and the record made complete, the suddenness of the break in the life-system would disappear. Nevertheless, it is also certain that these general unconformities indicate times of great change in physical geography, and therefore of climate, and therefore of rapid changes of organic forms; and therefore, also, they mark the natural boundaries of the great divisions of *time*.

Ages.—Again, the whole history of the earth is otherwise divided into seven *ages*, founded, with perhaps the exception of the first, on the culmination of certain great classes of organisms. These are: 1. The *Archæan* or *Eozoic Age*, represented by the Laurentian system of rocks; 2. The *Age of Mollusks*, or *Age of Invertebrates*, represented by the Silurian series of rocks; 3. The *Age of Fishes*, represented by the Devonian rocks; 4. The *Age of Acrogens*, or sometimes called the *Age of Amphibians*, represented by the Carboniferous rocks; 5. The *Age of Reptiles*, represented by the Secondary rocks; 6. The *Age of Mammals*, by the *Tertiary* and *Quaternary*; and, 7. The *Age of Man*, by the recent rocks.

In the accompanying diagram (Fig. 245), vertical height represents time, the strong horizontal lines divide the whole into eras, while the lighter lines, where necessary, separate the ages. The shaded spaces represent the origin, the increase and decrease, in the course of time, of the great dominant classes of animals and plants. To illustrate: The

[1] Dawn of animal life. [2] Old life. [3] Middle life. [4] Recent life.

class of reptiles commenced in the Carboniferous increased to a maximum in the Secondary, and again decreased to the present time. It

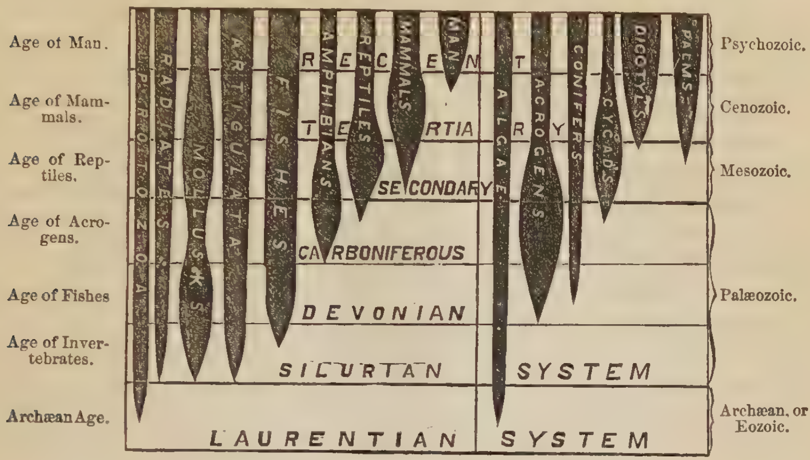


Fig. 245.

will be seen that the ages correspond with the eras, except in the case of the Palæozoic era. This long and diversified era is clearly divisible into three ages.

Subdivisions.—The subdivisions of eras and ages into *periods* and *epochs* are founded, as already explained (p. 201), on less general unconformity in the rock-system, and less conspicuous changes in the life-system. The names of periods are often, and of epochs are nearly always, local, and therefore different in different countries. We will, of course, use those appropriate to American geology. The table on page 201 represents, as far as periods, the classification used in this country. We have added epochs only in the uppermost part, viz., in the Tertiary and Quaternary.

We give, also (Fig. 246), an ideal diagram of the principal groups of strata which we shall notice, in the order of their superposition, indicating also the principal places of general unconformity.

Order of Discussion.—Many geologists take up the several epochs and periods of the history of the earth in the inverse order of their occurrence. Commencing with a thorough discussion of "*causes now in operation*," i. e., geological history of the present time, as that which is best known, they make this the basis for the study of the epoch immediately preceding, and which, therefore, is most like it. Having acquired a knowledge of this, the student passes to the preceding, and so on. This has the great advantage of passing ever from the better known to the less known, which is the order of induction. Other

geologists prefer to follow the natural order of events. This has the great advantage of bringing out the philosophy of the history—the law of evolution. The first method is the best method of *investigation;* the second method is the best method of *presentation.*

As in human history, so in the geological history, the recorded events of the earliest times are very few and meagre, but become more and more numerous and interesting as we approach the present time. Our account of the Archæan era will, therefore, be quite general, and will not enter into any subdivisions, although this era was very long. In the next era we will go into the description of the several ages, in the next into the periods, and in the next even into the *epochs.*

Prehistoric Eras.—Previous to even the dimmest and most imperfect records of the history of the earth there is, as already said (p. 265), an infinite abyss of the unrecorded. This, however, hardly belongs strictly to geology, but rather to cosmic philosophy. We approach it not by *written* records, but by means of more or less probable general scientific reasoning. We pass on, therefore, without pause to the lowest system of rocks containing the record of the earliest era.

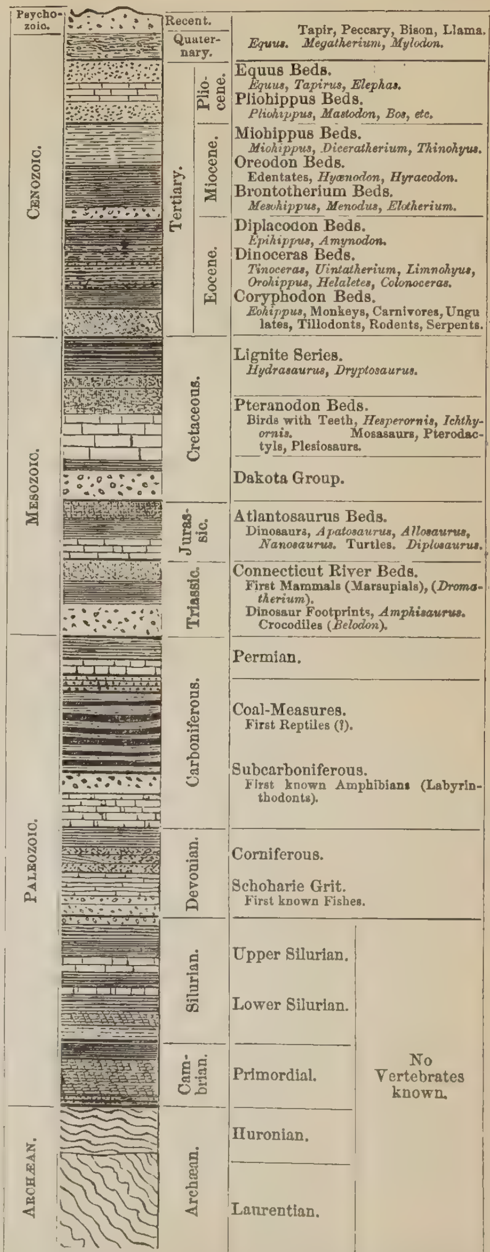


FIG. 246.—Section of the Earth's Crust, to illustrate Vertebrate Life in America. (Slightly modified from Marsh.)

CHAPTER II.

LAURENTIAN SYSTEM OF ROCKS AND ARCHÆAN ERA.

It is one of the chief glories of American geology to have established this as a distinct system of rocks and a distinct era.

It had been long known that beneath the lowest Palæozoic rocks there still existed strata of unknown thickness, highly metamorphic and apparently destitute of fossils. These had been usually regarded as lowermost Palæozoic—as the earliest defaced leaves of the Palæozoic volume. But the study of the Canadian rocks, by Sir William Logan, revealed the existence of an enormous thickness of highly-contorted, metamorphic strata, *everywhere unconformable with the overlying Potsdam* or lowest Silurian. More recent observations show this relation not only in Canada, but also in New York, on Lake Superior, in Nebraska, Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Texas, New Mexico, and Arizona. Nor is it confined to our own country, for the same unconformable relation has been found by Murchison on the west coast of Scotland, between the lowest Silurian (Cambrian) and an underlying gneiss, evidently corresponding to the Laurentian of Canada. Similar rocks, and in similar unconformable relation, have been found underlying the lowest Silurian in Bohemia, and also in Sweden and Bavaria, and many other places. Such general unconformity shows great and widespread changes of physical geography at this time. There seems no longer any doubt, therefore, that it should be regarded as a distinct system.

The following figures give the relation between the Palæozoic and the Laurentian in New Mexico, in Canada, and in Scotland.

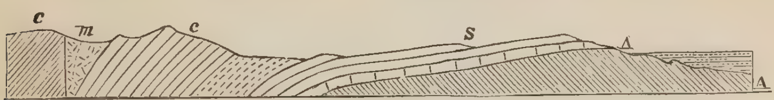


FIG. 247.—Section across Santarita Mountain, New Mexico: *c*, Carboniferous; *S*, Silurian; *A*, Archæan; *m*, metalliferous vein (after Gilbert).

These, then, are the *oldest known* rocks. They form the first volume of the recorded history of the earth. Yet they evidently are not the absolute oldest; evidently they do not constitute any part of the *primitive* crust. For they are themselves *stratified* or *fragmental*

rocks, and therefore formed from the *débris* of other rocks still older than themselves; and these last possibly from still older rocks. Thus,

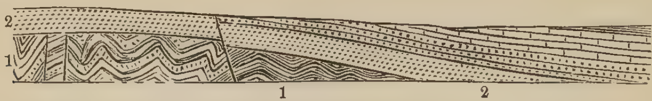


FIG. 248.—Section showing Primordial unconformable on the Archæan: 1, Archæan or Laurentian; 2, Primordial or Lowest Silurian (after Logan).

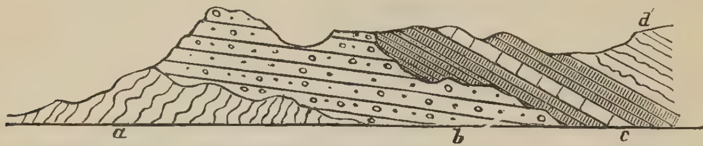


FIG. 249.—Diagram Section, showing the Structure of the North Highlands: *a*, Laurentian; *b*, Primordial; *c*, Lower Silurian (Jukes).

we search in vain for the so-called *primary* rocks of the original crust. Thus is it with all history. No *history is able to write its own beginning.*

Rocks.—There is nothing very characteristic in the rocks of the Laurentian system. They do not differ very conspicuously from those of other periods; consisting, in fact, only of altered sandstones, limestones, and clays. They are all, however, very much contorted and very highly metamorphic. In Canada they consist mainly of the *schist series*, passing on the one hand into gneiss and granite, and on the other into hornblendic gneiss, syenites, and diorites; of sandstones, passing into quartzites; and of *limestones*, passing into marbles, which are sometimes even intrusive. These together, in Canada, form a series of rocks at least 40,000 feet thick.

Interstratified with these are found immense beds of *iron-ore* 100 or more feet thick, and great quantities of *graphite*, sometimes impregnating the rocks, and sometimes in pure seams. In rocks of this age occur the great iron-beds of Missouri, of New Jersey, of Lake Superior, and of Sweden.[1] The quantity of iron found in these strata is far greater than in any other. It may be well called the Age of Iron.

The following figures show the contortion of the strata (Fig. 250), and the mode of occurrence of the iron (Figs. 251, 252).

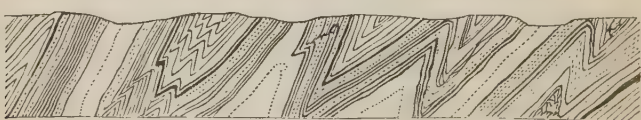


FIG. 250.—Contortion of Laurentian Strata (after Logan).

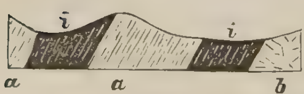


FIG. 251.

FIG. 252.

[1] See APPENDIX.

Area in North America.—1. These strata cover the greater portion of Labrador and Canada, and then, turning northwestward, extend to an unknown distance, but probably to the Arctic Ocean. The area forms a broad V, within the arms of which is inclosed Hudson's Bay. It may be seen on map, p. 289. This is the only extensive area known on the continent. 2. On the eastern slopes of the Appalachian chain undoubted patches are found as far south as Virginia, and a considerable area in this region is referred with much probability to the same. This is shown on map, p. 289, as the area left blank. Its further extension southward along the chain is still doubtful, though probable. 3. In the Rocky Mountain region extensive lines and areas of outcrop are known, trending in the general direction of the chain, and forming the axes of the great ranges. 4. Several small patches are also found scattered about in the basin of the Mississippi, apparently exposed by erosion.

Doubtless the Laurentian rocks are far more extended, but covered and concealed by other and later rocks. The area mentioned is the area of surface-exposure. It represents so much of Archæan sea-bottom as was subsequently raised into land, and not afterward again covered by sediments; or, if so covered, again exposed by erosion.

Physical Geography of Archæan Times.—As these are the oldest known rocks, we know nothing of the land from which they were formed. But since, during the rest of the geological history, the continent has developed from the north toward the south, it seems most probable that this earliest land lay still farther north, and disappeared when the Laurentian area was elevated into land.

Time represented.—The enormous thickness of these rocks (40,000 feet in Canada, and still greater in Bohemia and Bavaria) certainly indicates a very great lapse of time. It is probable that the Archæan era is longer than all the rest of the recorded history of the earth put together; and yet, precisely as in the beginnings of human history, the record is almost a blank. The events are few, and imperfectly recorded.

Evidences of Life.—We have already explained (p. 136) how iron-ore is at present accumulated. We have there shown that all accumulations of this kind now going on are formed by the agency of organic matter. It is almost certain that the same is true for all times, and therefore that iron-ore accumulations are the *sign* of the existence of organic matter, and quantity of the ore accumulated is a *measure* of the amount of organic matter consumed in doing the work. The immense beds of iron-ore found in the Laurentian rocks are, therefore, evidence of the existence of organisms in great abundance. That these organisms were *chiefly vegetable*, we have the further evidence derived from the great beds of graphite; for graphite, as we shall see hereafter is only the extreme term of the metamorphism of coal.

Of the existence of animal organisms the evidence is not yet complete, although it is probable that the lowest forms of Protozoa, such as Rhizopods, were abundant. We have seen that *limestones* are abundant among the Laurentian rocks. Now, the limestones of subsequent

Fig. 253.—Fragment of Eozoön, of the Natural Size, showing Alternate Laminæ of Loganite and Dolomite (after Dawson.)

geological epochs are almost wholly composed of the accumulated shelly remains of lower organisms, especially nullipores and coccoliths among plants, and rhizopods among animals.

The existence of rhizopods is believed by many to have been demonstrated. There have been found abundantly, in the Laurentian limestones of Canada, of Bohemia, of Bavaria, and elsewhere, large, irregular, cellular masses, which are believed by the best authorities to be the remains of a gigantic foraminiferous rhizopod. The supposed species has been called *Eozoön*[1] *Canadense*. Fig. 253 is a section of an Eozoönal mass, natural size, in which the white is the calcareous matter secreted by the rhizopod, and the dark corresponds to the animal matter of the rhizopod itself; and Fig. 254 a small portion of the same, magnified so as to show the structure of the cells.

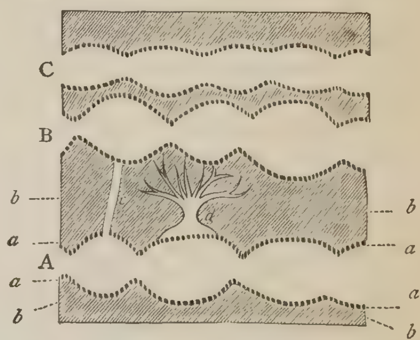


Fig. 254.—Diagram of a Portion of Eozoön cut vertically: *A, B, C*, three tiers of chambers communicating with one another by slightly constricted apertures; *a, a*, the true shell-wall, perforated by numerous delicate tubes; *b, b*, the main calcareous skeleton ("intermediate skeleton"); *c*, passage of communication ("stolon-passage") from one tier of chambers to another; *d*, ramifying tubes in the calcareous skeleton (after Carpenter).

There has been, and is still, much discussion as to the organic or mineral nature of these curious structures. If these irregular masses be indeed of animal origin, as

[1] Dawn animal.

seems most likely, it is evident that they belong to the lowest forms of compound protozoa—lower far than the symmetrically-formed foraminifera of later times. It is precisely in such almost amorphous masses of protoplasmic matter that, according to the evolution hypothesis, the animal kingdom might be expected to originate.

Some very obscure tracings, suggesting the *possible* existence of *marine worms*, have been found both in Canada and in Bohemia; but as yet we have no reliable evidence of any animals higher than the *protozoa.* It is impossible to say that other animals of low form did not exist; yet the absence of any reliable trace in rocks not more metamorphic than some of the next era, which are crowded with fossils of many kinds, seems to indicate a paucity, if not an entire absence, at this time, of such animals.

CHAPTER III.

PRIMARY OR PALÆOZOIC SYSTEM OF ROCKS AND PALÆOZOIC ERA.

General Description.

THIS is a distinct system of rocks, revealing a distinct *time-world*—a distinct *rock-system*, containing the record of a distinct *life-system.* The *rock-system* is distinct, being everywhere *unconformed to the Laurentian below and the Secondary above*—a bound volume—volume second of the Book of Time. The *life-system* is also equally distinct, being conspicuously different from that which precedes and that which follows. Whatever of life existed before, its record is too imperfect to give us a clear conception of its character. But in the Palæozoic the evidences of abundant and very varied life are clear; about 20,000 *species having been described.* It stands out the most distinct era in the whole history of the earth. The Archæan must be regarded as the *mythical period.* Here, with the Palæozoic, commences the true dawn of history.

Rocks—Thickness, etc.—The rocks of this system, although less powerful than the preceding, are also of enormous thickness compared with those of later geological times, being in the Appalachian region about 40,000 feet. It is believed that we are safe in saying that the time represented by them is equal to all subsequent time to the present.

There is nothing very characteristic in the rocks composing Palæozoic strata, though the practised eye may often distinguish them by their lithological character. Though strongly folded and highly meta-

morphic in some regions, these characters are not so universal as in the Laurentian.

In the United States the rocks of the whole system are generally conformable. In Europe, on the contrary, the principal divisions are usually unconformable. In this country, therefore, the subdivisions are founded almost wholly on change in the life-system; while in Europe the same subdivisions are founded on unconformity of the rock-system, as well as change in the life-system. Further, in this country, in passing from Pennsylvania, through New York, into Canada, we pass over the outcropping edges of the whole system, from the highest to the lowest; and finally into the Laurentian (Fig. 255). This, taken in connection with the conformity of the rocks, shows that during the Palæozoic the continent in this part was successively developed, from the north toward the south, by bodily upheaval of the Laurentian area and successive exposure of contiguous sea-bottom. In Europe the oscillations seem to have been more frequent and violent.

Fig. 255 is a section from Pennsylvania to Canada, showing the

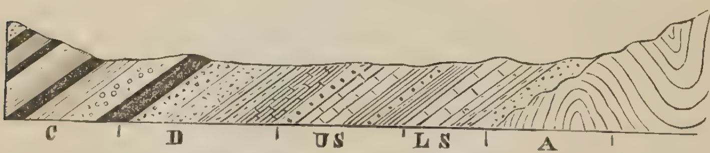


FIG. 255.—Ideal Section north and south from Canada to Pennsylvania: *A*, Archæan; *L S* and *U S*, Silurian; *D*, Devonian; *C*, Carboniferous.

relation of the subdivisions to each other, and the manner in which they lie on the Archæan. This will be better understood if the map on page 284 be at the same time carefully examined.

Area in the United States.—The area in the Eastern United States in which the country rock belongs to this system is seen in the map given on next page (Fig. 256). It may be stated roughly to embrace all that part included between the Great Lakes on the north, the Blue Ridge of the Appalachian chain on the east, the Prairies on the west, and Middle Alabama and Southern Arkansas on the south. It includes the richest portion of our country. Besides this great continuous area there are also areas of imperfectly known size and shape in the Rocky Mountain region, and on either side of the Sierra Nevada.

If we compare the Palæozoic rocks of the Appalachian region with the same in the central portion of the Mississippi basin, we observe the following changes as we go westward: (*a.*) The rocks in the Appalachian region are highly *metamorphic;* as we go westward, they become less and less so, until in the region about the Mississippi River they are wholly *unchanged.* (*b.*) In the Appalachian region they are strongly and complexly *folded;* as we go west, these folds pass into

gentle undulations, which die away into *horizontality* (*see* section on p. 254). (*c.*) In the Appalachian region they are about 40,000 feet

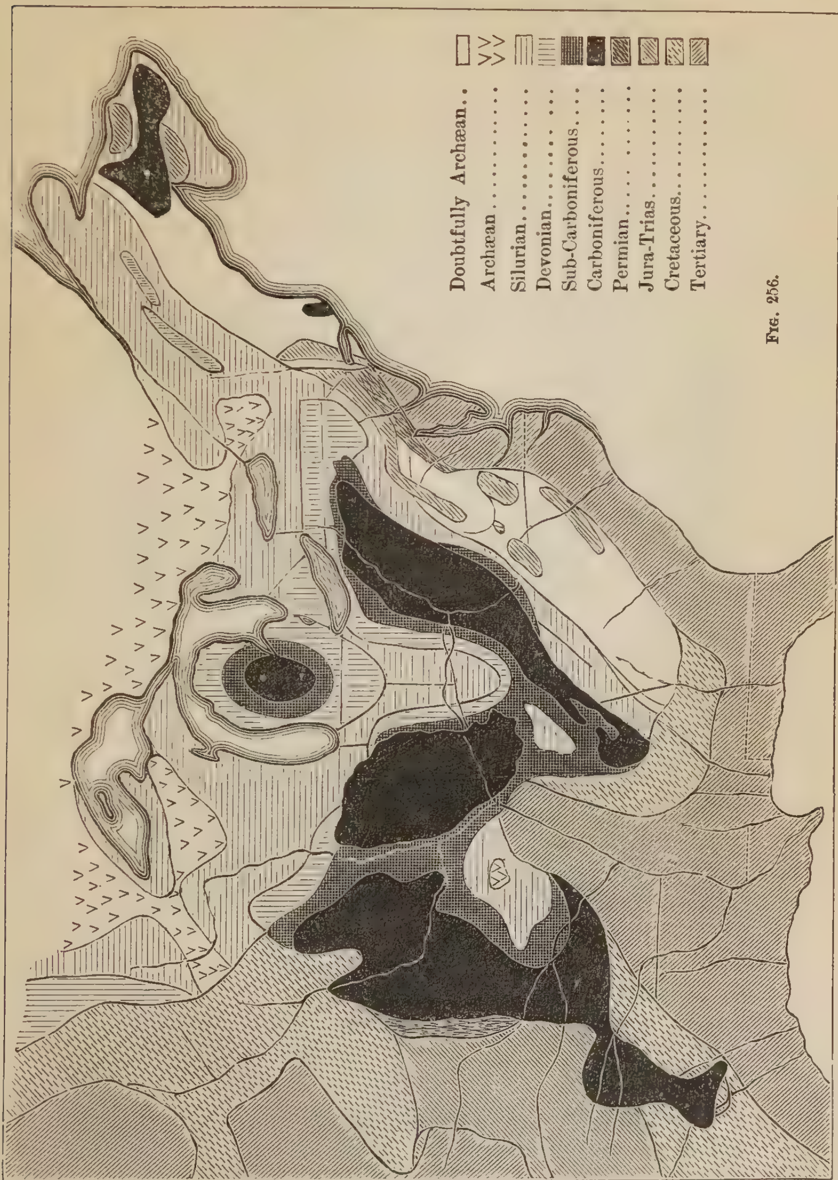


FIG. 256.

thick ; as we go west, they thin out until the whole series is only 4,000 feet at the Mississippi. (*d*). In the Appalachian region *grits and sand-*

stones and shales predominate greatly over limestones ; as we go west, the proportion of *limestone* increases, until these are the *predominating rocks.* These four changes are closely connected with each other, and all with the formation of the Appalachian chain, as we have already explained in the chapter on Mountain-Formation (p. 262, *et seq.*).

Physical Geography of the American Continent.—At the *beginning* of the Palæozoic era the land was substantially the Laurentian or Archæan area, already described, excepting Archæan areas subsequently exposed by erosion.[1] From this nucleus, *during* Palæozoic times, the continent was developed southward, until, at the end, it included also the *Palæozoic area* just described. The accompanying map (Fig. 257)[2] gives approximately the area of land at the *beginning.*

FIG. 257.—Existing Seas, Lakes, etc., shaded black; Portions of Continent then covered, lighter; Land of that Time left white; where Outline known, surrounded with Full Line; when doubtful, by Dotted Line.

The map of the physical geography of Cretaceous times (p. 472) gives somewhat less approximately its area at the end. It will be seen that the continent was already sketched out at the beginning, and steadily developed throughout its continuance. There is much reason to believe that a considerable body of land existed at this

[1] See APPENDIX.

[2] A map similar to the above, but containing also small scattered patches of Archæan exposures, is sometimes spoken of as an Archæan map of North America, or map of Archæan land. It must be borne in mind, however, that it represents indeed land of Archæan *strata,* but, for that very reason, not of Archæan *time*, but of Silurian time.

time to the east of the Appalachian region, much of which afterward disappeared by subsidence. It is only thus that we can explain the thick strata of this region.

Subdivisions.—The Palæozoic era is divided into three *ages*, which are embodied in three distinct subordinate rock-systems. These ages are each characterized by the dominance of a great class of organisms. They are: 1. The *Silurian System*, or *Age of Invertebrates*, or sometimes called *Age of Mollusks;* 2. The *Devonian System*, or *Age of Fishes;* and, 3. The *Carboniferous System*, or *Age of Acrogens and Amphibians.* These are three chapters in the Palæozoic volume.

These three systems are generally conformable with each other in the Palæozoics of the United States, as we have already shown, but elsewhere they are often unconformable. Before taking up the first in the order of time, viz., the Silurian, it is necessary to say something of the *interval* which in our record separates the Archæan from the Palæozoic era.

The Interval.—We have already seen that the lowest Silurian lies unconformably on the upturned and eroded edges of the crumpled strata of the Laurentian. We have also shown (p. 179) that unconformability indicates always an oscillation of the earth's crust at the observed place. More definitely it indicates an upheaval, by which the lower series of rocks became land-surface, and were at the same time, perhaps, crumpled; then a long period *unrecorded* at that place, during which the land was eroded and the edges of the crumpled rocks were exposed; then a subsidence, and the deposit of the upper series of rocks on these exposed edges. Now, oscillation necessitates increase and decrease of land-surface. Evidently, therefore, such increase and decrease of land-surface took place in the unrecorded interval between the Archæan and Palæozoic eras; and the length of this unrecorded interval is measured by the amount of erosion which the Laurentian underlying the lowest Palæozoic has suffered. We have stated that the land at the beginning of the Silurian age was approximately the Laurentian area. The shore-line of the earliest Palæozoic sea was the line of junction between the Silurian and Laurentian (*see* map, p. 289). *But this was not the shore-line at the end of the Archæan* time. Evidently this shore-line was much farther south; evidently the land-area was much greater at the end of the Archæan than at the beginning of the Silurian. The Archæan era was closed by the *upheaval* into land-surface and the crumpling of the strata of the whole Laurentian area, and *much more.* Then followed an interval of which we know nothing, except that it was of long duration, during which the crumpled Laurentian strata forming the then land-surface were *deeply eroded.* Then, at the end of this interval came a *subsidence* down to the shore-line already indicated as the Silurian shore-line, and the Silurian age commenced, its first sediments being

of course deposited on the exposed edges of the submerged Laurentian rocks.

I have attempted to illustrate these facts by the following diagrams (Fig. 258), in which *c* represents a section north and south through the Laurentian and Palæozoic rocks. The crumpled Laurentian strata, with their outcropping eroded edges, are seen to underlie the lowest Silurian to some distance. This is the actual condition of things. The manner

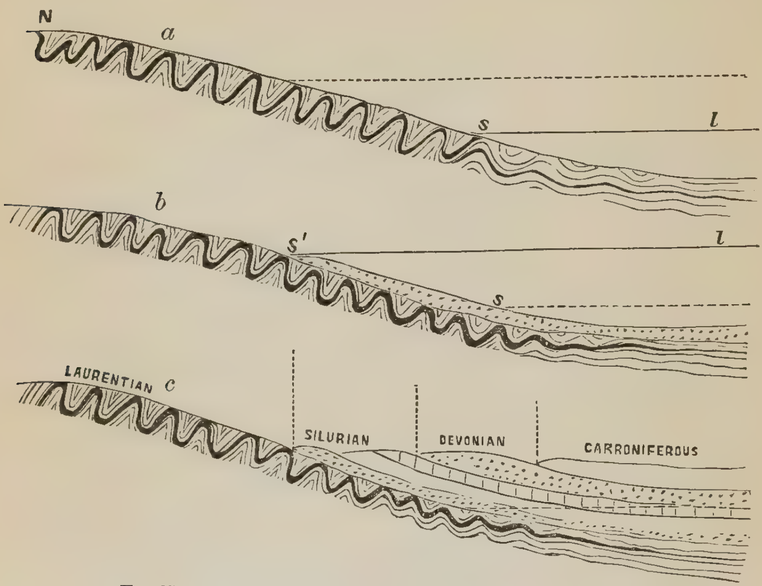


FIG. 258.—Ideal Sections, showing how Unconformity is produced.

in which this condition was brought about is shown in *a* and *b*. In *a* we have represented the supposed condition of things during the interval, *s l* being the sea-level, and *s* the shore line; in *b* the condition of things at the end of the interval or beginning of the Silurian, when by subsidence the shore-line had been shifted northward to *s'*, and on the exposed edges of the strata of the previous land-surface, from *s* to *s'*, Silurian sediments had begun to deposit.

We have spoken thus far only of the unconformity of the New York rocks on the Canadian rocks. This phenomenon may be explained, as we have seen, by local oscillations, with increase and decrease of land-area during the lost interval. But, when we remember that the same unconformity is found in the most widely-separated localities, over the whole area of the United States, we are forced to the conclusion that the lost interval, as compared with the Silurian, was probably a *continental* period—a period of widely-extended land composed of

Laurentian rocks. The whole of this land disappeared by submergence at the beginning of the Silurian, except the Canadian area, and probably a considerable area in the Basin region, and perhaps a few islands or larger areas in Silurian seas between.

In all speculations on the origin of the animal kingdom by evolution, it is very necessary to bear in mind this *lost interval*, for it was evidently of great duration.

SECTION 1.—SILURIAN SYSTEM: AGE OF INVERTEBRATES.

The Rock-System.—The rocks of this age have been carefully studied in England, by Sedgwick and Murchison; in Russia and Sweden, by Murchison; in Bohemia, by Barrande; and in New York, by Hall. The divisions and subdivisions established by these geologists have become the standard of comparison elsewhere. The system was first clearly defined by Murchison in Wales. The name Silurian (from Silures, the Roman name for the inhabitants of Wales) was given by him, and is now universally adopted. But the most perfect examples are, perhaps, those found in Bohemia and in New York. We have already given (Fig. 255) a section of the Palæozoics of New York, including, of course, the Silurian. Some geologists call the lower portion *Cambrian*—a name given by Sedgwick.

Subdivisions.—The following table gives the divisions and subdivisions of the Silurian system and the corresponding *periods* of this age in this country:

Upper Silurian.	Oriskany	Period.
	Lower Helderberg	"
	Salina	"
	Niagara	"
Lower Silurian.	Trenton	"
	Canada	"
	Primordial	"

The larger divisions, viz., Lower and Upper Silurian, are generally recognized; also, the Primordial is generally recognized; by some as a subdivision of the Silurian, by others as more distinct than the other periods and as synonymous with Cambrian. The subdivisions are, with this exception, local, each country having its own; but they are synchronized, as far as possible, by comparison.

Character of the Rocks.—The Silurian, like nearly all rocks, are greatly disturbed and metamorphosed in mountain-regions, though less so than the Laurentian; but in Sweden and Russia, and in the valley of the Mississippi, Silurian rocks are found in their original horizontal position, and not greatly changed from their original sedimentary condition.

Area in America.—By turning to the map (p. 289) it will be seen: 1. That the Silurian is attached to the Laurentian nucleus as an irregu-

lar border on the outer side of the V-shaped area; 2. Again, the Appalachian Laurentian region is also bordered on the west side by Silurian; 3. Also we observe large patches in the interior—one about Cincinnati, another occupying the southern portion of Missouri and northeastern portion of Arkansas, and one in Middle Tennessee; 4. Also, large areas are known to occur in the Rocky Mountain region and in the Basin region between the Wahsatch Mountain and the Sierra; but their outlines are yet too little known to describe them accurately.

Physical Geography.—At the beginning of the Silurian, as already said, the land was approximately the Laurentian area (Fig. 257). The Silurian, which embraces the great V-shaped Laurentian area on the southeast, south, and southwest, was then the sea-bottom border of the coast of that Silurian continent. The Silurian bordering the Appalachian Laurentian was also then a sea-bottom bordering the Silurian continent in that region. It is probable, also, that the Silurian of the Rocky Mountain region also borders Laurentian areas, and these areas represent Silurian continents, and the Silurian border the marginal sea-bottom of that time. The other patches mentioned in the interior were probably bottoms of open seas.

Now, the Silurian area represents so much of Silurian sea-bottoms as were raised into land-surfaces during or at the end of Silurian times, and not subsequently covered by sea.[1] Therefore, at the beginning of Silurian times the land was the Laurentian area; while at the end of the Silurian times the land was increased by the addition of the Silurian area. This addition was not all made at once, but very gradually. The steps of this increase have been carefully studied in New York. The following map (Fig. 259) shows the principal successive steps, as does also the section (Fig. 255) with which it should be compared. Inspection of these figures shows not only the Silurian bordering the Laurentian, but the rocks of the several periods bordering each other successively; so that in walking from Pennsylvania to Canada, or to the Adirondack Mountains of New York, we successively walk over the Carboniferous, the Devonian, the Silurian, and the Laurentian; and in the Silurian over rocks of the successive periods, from the highest to the lowest. This plainly shows that during Silurian times the continent (Laurentian area) was slowly upheaved, and contiguous sea-bottoms successively added to the land, and the shore-line gradually pushed southward from the Canadian region, and probably westward from the land-mass along the Appalachian. Of course, therefore, the *oldest* Silurian shore-line was the most northern and eastern. This is the *primordial beach.*

Primordial Beach and its Fossils.—As already stated, the elementary character of this treatise renders it impossible to take the several

[1] This is true as a broad, general fact; but patches of Silurian may also be exposed by *removal* of later deposits by erosion.

periods of this age. We must confine ourselves to a general description of the age only. But there is so peculiar and special an interest connected with the dawn of life on the earth, that, before taking up the life-system of the whole age, it seems necessary to say something of the *earliest fauna.*

We have seen that at the beginning of Silurian times a large V-shaped mass of land occupied the region now embraced by Canada and Labrador, and stretched northwestward to an unknown distance, the two arms of the V being nearly parallel to the two present shores of the American Continent; further, that a land-mass of extent unknown occupied the position of the eastern slope of the Appalachian chain; also, that land of unknown extent occupied the position of the Rocky Mountains; and the continent was thus early sketched out. Now, southward of the first-mentioned land-area and between the other two

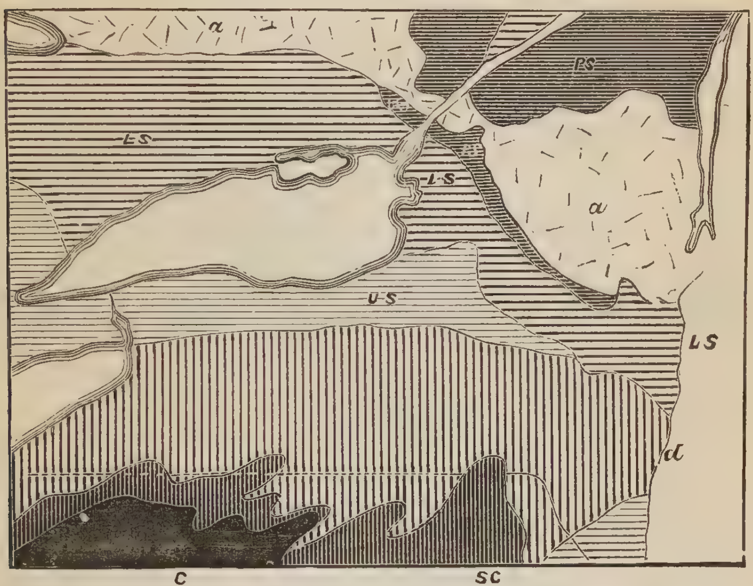


FIG. 259.—Geological Map of New York: *a*, Archæan; *PS*, Primordial; *LS*, Lower Silurian; *US*, Upper Silurian; *d*, Devonian; *SC*, Subcarboniferous; *C*, Coal-measures.

there was a great interior sea, which we will call the *Interior Palæozoic Sea.* The shores of that sea beat upon the continental masses north, east, and west, and accumulated, on exposed places, a *beach.* Patches of that earliest beach still remain. They are found, of course, closely bordering the Laurentian rocks, Canadian and Appalachian, and lying unconformably upon them. They are the primordial sandstones and slates of Canada, New York, Pennsylvania, Virginia, and probably Tennes-

Fig. 260.

Fig. 263.

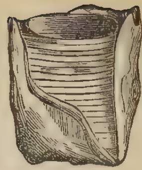


Fig. 264.

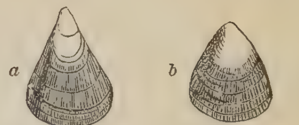


Fig. 261.

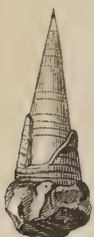


Fig. 265.

Fig. 262.

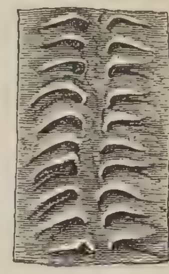


Fig. 266.

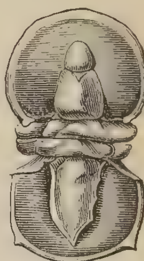


Fig. 269.

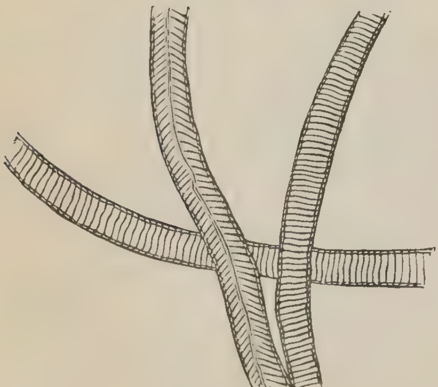


Fig. 267.

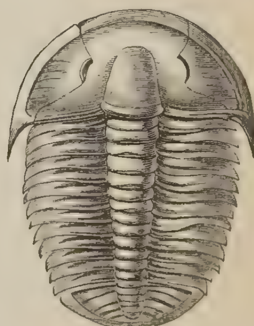


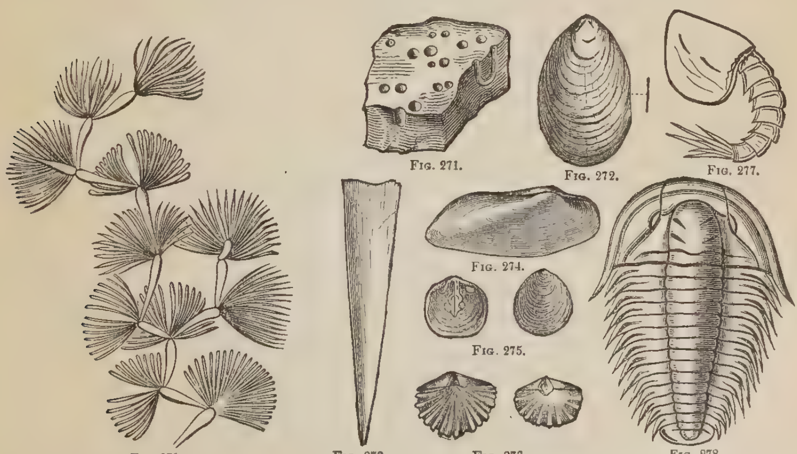
Fig. 268.

Figs. 260–69. — American Primordial Fossils: 260. Plant: Scolithus linearis (after Hall). 261. Brachiopod: *a* and *b*, Lingula acuminata (after Logan). 262. Lingula antiqua (after Hall). 263. Gasteropod: Ophileta compacta. 264. Cephalopod: Orthoceras. 265. Pteropod: Hyolithes primordialis (after White). 266. Tracks: Crustacean (after White). 267. Trail of Marine Worm (after Logan). 268. Conocoryphe Kingii (after White). 269. Agnostus interstrictus (after White).

see, and possibly Georgia. The fact that these are indeed remnants of a beach is proved by the existence, in almost every part, of *shore-marks* of all kinds—such as ripple-marks, sun-cracks, worm-tracks, worm-borings, broken shells, etc.

This, then, is the old primordial beach. It is of the extremest interest to the geologist because it marks the outline of the earliest Silurian sea, and contains the remains of the earliest Silurian fauna. Indeed, we may say it contains the remains of the *earliest known fauna.* It is true, the lowest Rhizopods probably existed in Archæan times, but these cannot be said to constitute a fauna. With the very commencement of Silurian times, however, we find at once a considerable variety of animal forms.

What, then, was the character of this earliest fauna and flora? If we could have walked along that beach when it was washed by primordial seas, what would we have found cast ashore? *We would have found the representatives of all the great types of animals except the vertebrata.* The Protozoa were then represented by *sponges* and Rhizopods; the Radiates by *Hydrozoa* (graptolites) and Cystidean *Crinoids;* the mollusks by *Brachiopods*, *Gasteropods* (Pleurotomaria), *Pteropods*, and even *Cephalopods* (orthoceras); and the Articulates by *Crustaceans* (trilobites, etc.) and *Worms*. Plants are represented by *Fucoids.* These widely-distinct classes are already clearly differentiated and somewhat highly organized. Nor is the fauna a meagre one in number of species. In the United States and Canada alone about 200 species are already known, of which nearly 100 are *trilobites.* About a dozen species of plants are also known. When we recollect the great



Figs. 270–278.—Foreign Primordial Fossils: 270. Oldhamia antiqua, probably a plant. 271. Arenicolites didymus, Worm-tubes. 272. Lingulella ferruginea. 273. Theca Davidii. 274. Modiolopsis solvensis. 275. Orthis Hicksii. 276. Obolella sagittalis. 277. Hymenocaris vermicauda. 278. Olenus macrurus.

age of these rocks and their usual metamorphism, and the fragmentary character of all fossil fauna, it seems certain that great abundance and variety of life existed already in these early seas. Of this life the trilobites, by their size, their abundance, their variety, and their high organization, must be regarded as the dominant type. Among the largest trilobites known at all are some from this period. The Paradoxides, represented in Figs. 279 and 280, attained a length of twenty

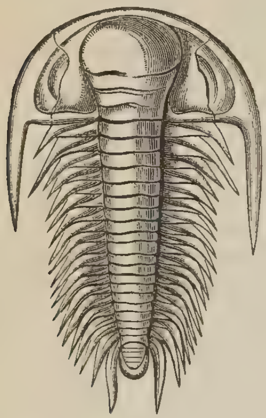


FIG. 279.—Paradoxides Bohemicus, Foreign.

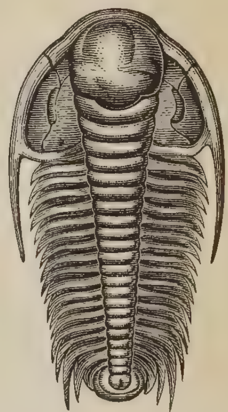


FIG. 280.—Paradoxides Harlani, × ⅛ (after Rogers), American.

inches. English beds of the same age furnish specimens of the same genus two feet long.

We give in the above figures a few of the more remarkable primordial forms taken from the rocks of this country, and of foreign countries. They are intended only to give a general idea of the fullness and variety of the primordial life; the affinities of these fossils will be discussed hereafter.

General Remarks on First Distinct Fauna.—There are several points of great philosophic interest suggested by the nature of these first organisms:

1. Plants in this, and in all other geological periods, are far less numerously represented in a fossil state than animals. This cannot be because animals were more abundant than plants, for since the animal kingdom subsists on the vegetable kingdom, and since every animal consumes many times its own weight of food, plants must have been always more abundant than animals. The true reason of the greater abundance of animal remains is to be found in the fact that the hard parts of animals are far more indestructible than any portion of vegetable tissue.

2. At the end of the Archæan times—when the Archæan volume

closed—we find only the lowest Protozoan life. But with the opening of the next era, apparently with the first pages of the next volume, we find already all the great types of structure except the vertebrata. And these not the lowest of each type, as might have been expected, but already trilobites among Articulata, and Cephalopods among Mollusca—*animals which can hardly be regarded as lower than the middle of the animal scale.*

We must not hastily conclude, however, that these widely-divergent and highly-organized types originated together at once. We must remember that between the Archæan and Palæozoic there is a *lost interval* of enormous duration. Evidently, therefore, the Primordial fauna is *not the actual first fauna.* Evidently we have not yet recovered the leaves in which is recorded the gradual differentiation of these widely-distinct types. All this must have taken place *during the lost interval.*

But if, on the other hand, we suppose, as many do, that evolution proceeds always "with equal steps," then we are forced to the very improbable conclusion that the lost interval is equal to all geological times which followed to the present; for the differentiation of types which occurred during that interval is equal in value to all that has taken place since.

Therefore, we are compelled to admit that there have been in the history of the earth periods of rapid change in physical geography, and periods of comparative quiet in this respect; that, corresponding with these, there have been also periods of rapid evolution of the organic kingdom, developing new forms, and periods in which forms are more stationary. The periods of rapid change are marked by unconformity, and are therefore unfortunately often lost.

As we proceed, we will probably find many examples of rapid change which must be accounted for in a similar manner.

General Life-System of the Silurian Age.

There were evidently extraordinary abundance and variety of life in the Silurian. These early seas literally swarmed with living beings. The quantity and variety of life—the number of *individuals* and of *species*—were probably not less than at the present time; though orders, classes, and departments, were less diversified. Over 10,000 species have been described from the Silurian alone (Barrande); and these must be regarded as only a small fragment of the actual fauna of the age. In certain favored localities, the number of species found in a given area of a single stratum will compare favorably with the number now existing in *an equal area* of our present sea-bottoms. Yet, in all this teeming life there is not a single species similar to any found in any other geological time. And not only are the species peculiar, but even the genera, the families, and the orders, are different from those now existing.

Fig. 281.

Fig. 282.

Fig. 283 *a*.

Fig 283 *b*.

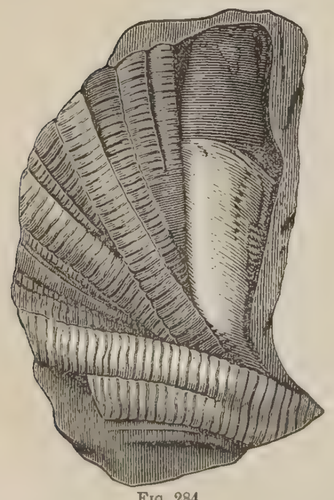


Fig. 284.

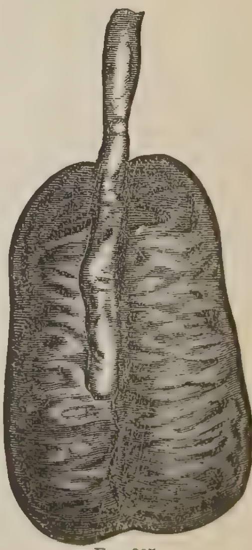


Fig. 285.

Figs. 281-285.—Silurian Plants: 281. Sphenothallus angustifolius (after Hall). 282. Buthotrephis succulens (after Hall). 283. *a* and *b*, Buthotrephis gracilis (after Hall). 284. Arthrophycus Harlani (after Hall). 285. Cruziana bilobata (after Hall).

We can give only a very brief sketch of this early life, touching only the most salient points, especially such as throw light on the great question of evolution.

Plants.

The only plants yet found are the lowest forms of cellular cryptogams, viz., *marine algæ* or sea-weeds.[1] It is difficult, from the impressions left by these, to determine genera, much more species, with any degree of certainty. We shall, therefore, call them by the general somewhat indefinite name of *Fucoids* (*Fucus*, tangle or kelp), or Fucus-like plants. As already stated, plants are far less abundantly and perfectly preserved than animals, on account of their want of a skeleton.

Animals.

Protozoans.—The large, *irregular* masses which are called Eozoön seem entirely characteristic of Archæan times. They are replaced in the Silurian age by the more regular *sponges*. Of these, the most characteristic Silurian genera are Stromatopora and Receptaculitis. They seem to have formed large coralline masses, which are regarded either as calcareous sponges, or as compound Rhizopods like Eozoön.

Fig. 286.—Stromatopora rugosa.

Radiates, Corals.—Corals were very abundant, forming often whole rock-masses, as if they, while living, formed *reefs*. These, if they in-

[1] Recently a few vascular cryptogams have been found in the Middle Silurian both of this country and of Europe.—Lesquereux, *Amer. Jour. of Science*, 1878, vol. xv., p. 149.

dicate warm seas, show a great uniformity of temperature, since they are found in all portions of the earth alike.

The corals of the Silurian age belong principally to three families,

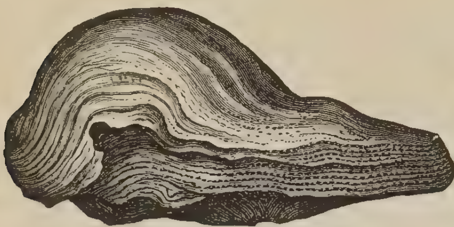


FIG. 287 *a*.

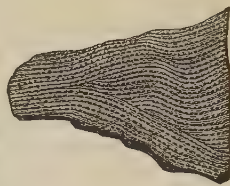


FIG. 287 *b*.

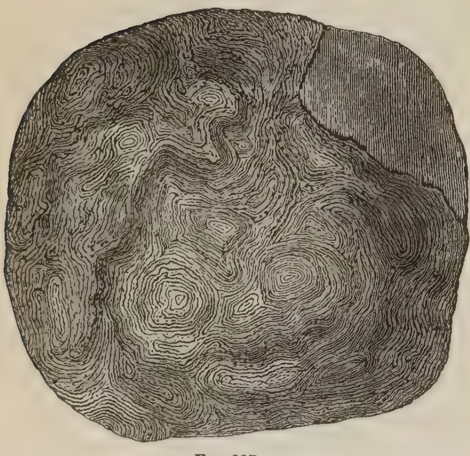


FIG. 287 *c*.

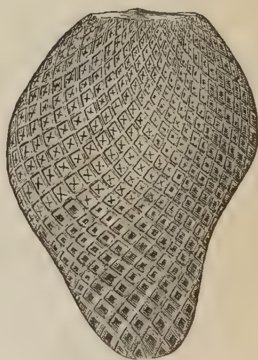


FIG. 288.

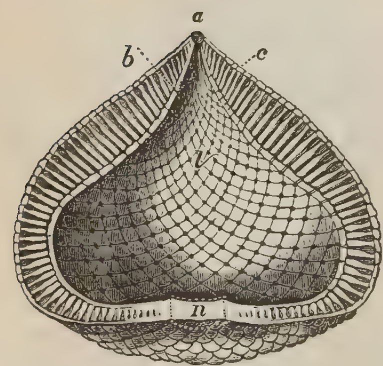


FIG. 289.

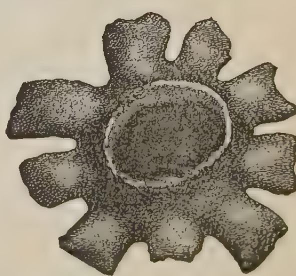


FIG. 290.

FIGS. 287–290.—SILURIAN PROTOZOANS: 287. *a*, Stromatopora concentrica; *b*, section of same; *c*, view from above (after Hall). 288. Receptaculitis formosus (after Worthen). 289. Diagram showing Strucure of Receptaculitis (after Nicholson). 290. Brachiospongia Rœmerana × ½ (after Marsh).

viz., *Cyathophylloids*, or *cup-corals; Favositidæ*, or *honey-combed corals;* and *Halysitidæ*, or *chain-corals.* They are remarkable in not usually being profusely and widely branched like most modern corals, but consisting mostly of masses of parallel or nearly parallel columns. In *Cyathophylloids* the corals are sometimes separate and of a horn-like form, and sometimes aggregated in large, rough, columnar masses (Rugosa). Their upper portions are *cup-shaped*, and the radiating *laminæ* are very distinct. In *Favositids* the hexagonal parallel columns are divided somewhat minutely by horizontal plates (Tabulatæ), giving a cellular structure which may be finer or coarser. The Halysitids seem to be made up of small, hollow, flattened columns with imperfect septa, united to form inosculating plates which on section have the appearance of chains crossing in all directions. These are also minutely tabulated. The Syringoporoids are similar to the Halysitids, except that the hollow columns are cylindrical and connect with each other only in places.

The following are some of the more characteristic species of these families.

FIG. 291.

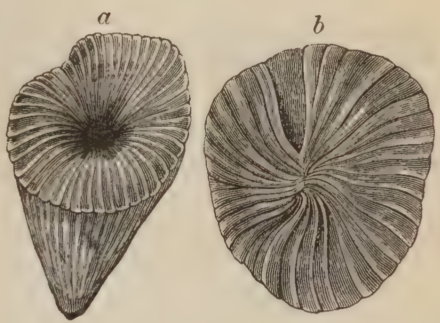


FIG. 292.

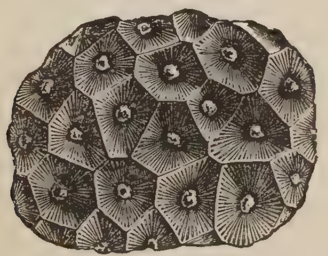


FIG. 293.

FIGS. 291-293.—CYATHOPHYLLOID CORALS: 291. Lonsdaleia floriformis (after Nicholson). 292. *a* and *b*, Zaphrentis bilateralis (after Hall). 293. Strombodes pentagonus (after Hall).

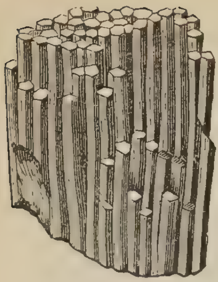


FIG. 294.

FIG. 294 *a*.

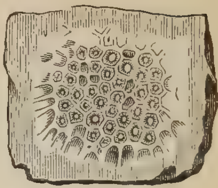


FIG. 294 *b*.

FIG. 295.

FIG. 296.

FIGS. 294–296.—FAVOSITID AND HALYSITID CORALS: 294. Columnaria alveolata; *a*, vertical; *b*, cross-section (after Hall). 295. Syringopora verticillata. 296. Halysites catenulata (after Hall).

There are many other forms than those mentioned above, but their affinities are little understood, and many are not true corals, but Polyzoa and sponges. Nearly all the corals of Silurian, in fact of Palæozoic times, fall under two orders—*Rugosa* and *Tabulata*. The Cyathophylloids are Rugosa, the other families mentioned are Tabulata. The Rugosa are characteristic of the Palæozoic; the Tabulata are also nearly extinct: they have only one family living, viz., the millipores. The Rugosa differ from modern star-corals in having their radiating septa in multiples of four, while modern star-corals have theirs in multiples of five or six. Hence star-corals have been divided into two types—a Palæozoic and a Neozoic—the one four-parted (quadripartita), the other six-parted (sexpartita).

Hydrozoa.—The *perfect* forms of this class, viz., Medusæ, or jelly-fishes, are so soft and perishable that, with one or two exceptions in the Mesozoic rocks, they are not found preserved at all in the strata of

any geological period. They may or may not have existed at this time; probably they did not. But the *larval* form of most, if not all, Medusæ is a compound polypoid animal, forming a minutely-branching, horny, or coralline axis. These minutely-branching axes are strung on each side with cells, in which are inclosed little polypoid animals. They grow in still, quiet waters, and are often mistaken by the unscientific for sea-weed. These, by their composition, are well adapted for preservation, and it is this larval form, therefore, only that we might expect to find.

Fig. 297.

Fig. 298 *a*.

Fig. 298 *b*.

Fig. 299.

Figs. 297–299.—Living Hydrozoa: 297. Sertularia pinnata: *a*, natural size; *b*, enlarged. 298. *a* and *b*, Different Forms of Sertularia. 299. Plumularia.

Now, in very fine shales of Silurian age, especially of Lower Silurian, are found abundantly beautiful impressions of an organism which is most probably a compound Hydrozoan allied to Sertularia of the present day. They are called *graptolites*. Sometimes the cells are arranged on one side of the axis, sometimes on both sides, sometimes the axis is divided. Whatever be their affinities, they are of great importance, inasmuch as they are *entirely characteristic of the Silurian*

age, and *those with cells on both sides, of the Lower Silurian.* The twin graptolites (Fig. 302) are also wholly characteristic of Lower Silurian.

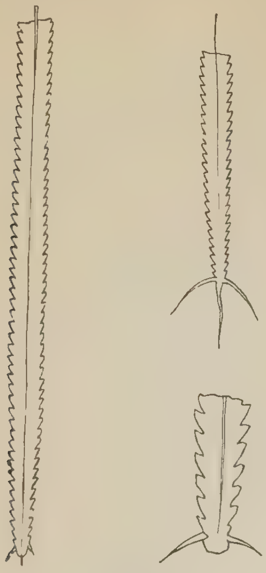


Fig. 300.

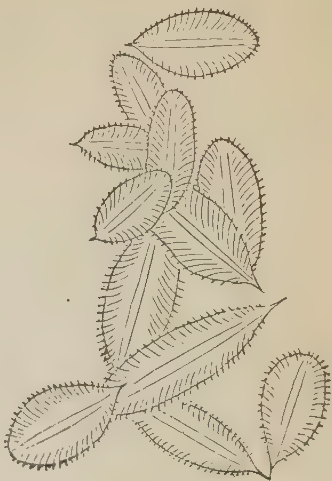


Fig. 301.

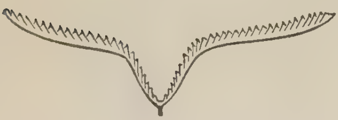


Fig. 302.

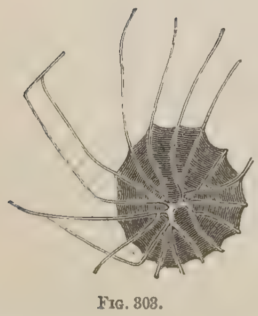


Fig. 303.

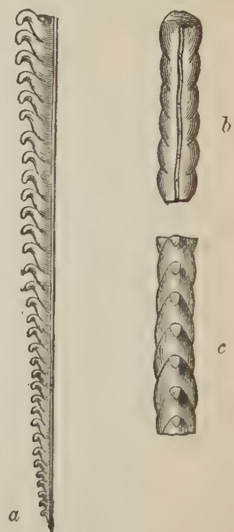


Fig. 304.

Figs. 300–304.—Graptolites: 300. Diplograptus pristis (after Nicholson). 301. Phyllograptus typus (after Hall). 302. Didymograptus V-fractus (after Hall). 303. Graptolithus Logani (after Hall). 304. Monograptus priodon; *a*, side-view; *b*, back-view; *c*, front-view, showing opening (after Nicholson)

Fig. 305.

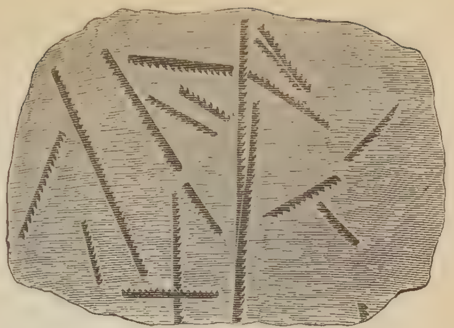
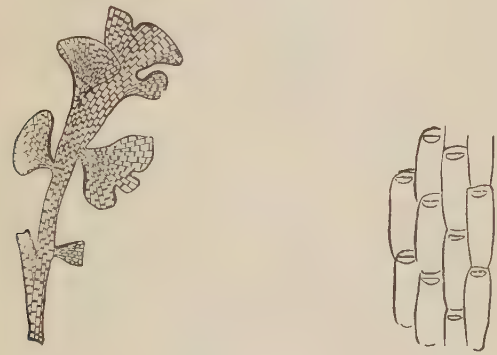


Fig. 306.

Figs. 305, 306.—Graptolites: 305. Dendrograptus Hallianus (after Hall). 306. Graptolites Clintonensis (after Hall).

Polyzoa.—There are many kinds of compound coralline animals, probably allied to the Bryozoa (sea-mats) of our present seas, found in the Silurian. The doubtful affinities of these Palæozoic forms, and the difficulty of separating them sharply from certain forms of true corals on



a *b*

Fig. 307.—Living Polyzoa: Flustra truncata: *a*, natural size; *b*, enlarged to show the cells.

the one hand, and from certain forms of graptolites on the other, seem to require their notice in this connection, although their affinities are probably molluscoid. Two of the Silurian forms are represented on page 308, Figs. 308 and 309.

Echinoderms.—During Silurian times the class of Echinoderms was represented principally by *Crinoids*. A Crinoid is a stemmed Echinoderm, usually with branching arms. The animal consists of a long *jointed* stalk, rooted to the sea-bottom, and bearing atop a rounded or

pear-shaped body, covered with calcareous plates (calyx), from the margin of which spring the arms, which may be long and profusely branched,

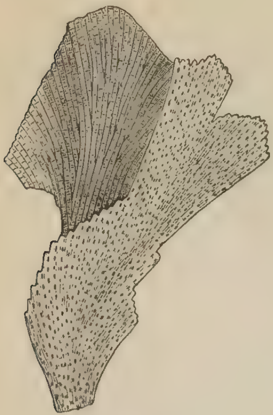


Fig. 308.

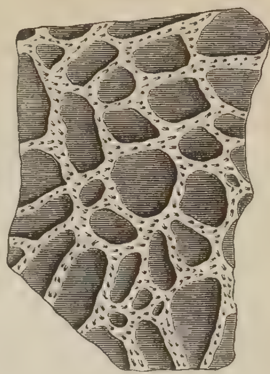


Fig. 309 *a*.

Fig. 309 *b*.

Figs. 308 and 309.—Silurian Polyzoa: 308. Fenestella elegans (after Hall). 309. Alecto auloporoides (after Hall).

or short and simple, or absent altogether. In the middle of the calyx, between the bases of the arms, is placed the mouth. Their general structure and appearance will be better understood by examination of the following figures of living Crinoids.

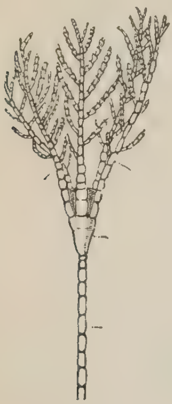


Fig. 310.

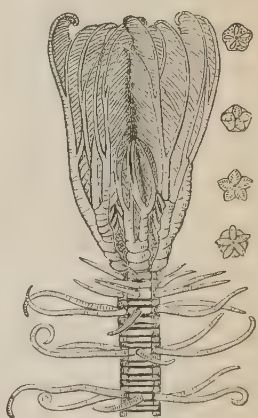


Fig. 311.

Figs. 310 and 311.—Living Crinoids: 310. Rhizocrinus Lofotensis (after Thompson). 311. Pentacrinus Caput-Medusæ.

At present, leaving out the Holothurians, or sea-cucumbers, which, having no shell, are little apt to be preserved as fossils, the class of

Echinoderms may be conveniently divided into three orders, viz.: the *Echinoids*, or sea-urchins; the *Asteroids*, or starfishes; and the *Crinoids.* The members of the first and second orders are free moving, while those of the third are stemmed. Of these orders the Crinoids are the lowest, as proved not only by their simpler organization, but also by the fact that a living Crinoid, the Comatula, is attached when young, but free when mature.

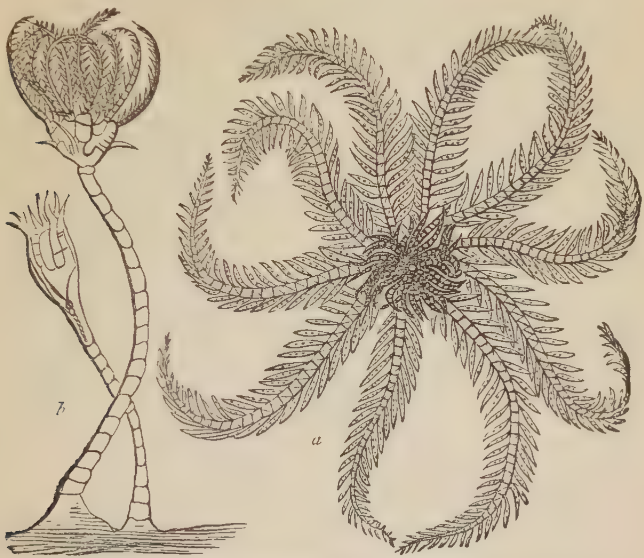


FIG. 312.—A Living Free Crinoid—Comatula rosacea, the Feather-Star: *a*, free adult; *b*, fixed young (after Forbes).

Now, in Silurian times, the stemmed Echinoderms are very abundant, while the free are very rare: at the present time, on the contrary, the reverse is the case. Thus, in the course of time, the former decreased until they are now almost extinct, while the latter increased until they are now very abundant. If we take the abundance of Echinoderms during geological times as constant, and represent the course of

FIG. 313.—Diagram showing the General Distribution in Time of Stemmed and Free Echinoderms.

time by the absciss *A B* (Fig. 313), and the abundance by distance from *A B* to *C D*, then the parallelogram would represent this fact. If, now, we draw the diagonal, *C B*, then the shaded triangle would

represent the stemmed, and the unshaded the free, and the diagonal the line of decrease of the one and increase of the other; and the whole figure the general relations of the two sub-classes throughout time. In the Palæozoic the stemmed predominate; in the Mesozoic the two are equally represented; in modern times the free predominate.

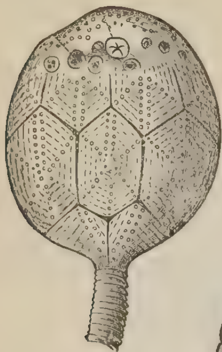


Fig. 314.

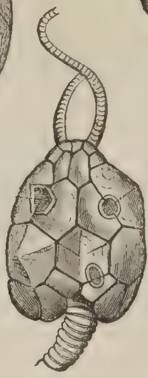


Fig. 315.

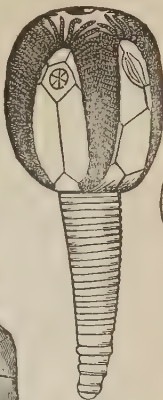


Fig. 316.

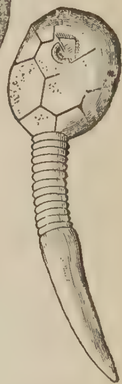


Fig. 317.

Fig. 318 *a.*

Fig. 318 *b.*

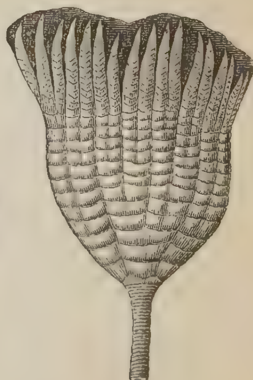


Fig. 319.

Figs. 314–319.—Silurian Crinoids: 314. Caryocrinus ornatus. 315. Pleurocystitis squamosus. 316. Pseudocrinus—a cystid restored (after Lütken). 317. Lepadocrinus Gebhardii. 318. Glyptocrinus decadactylus (after Hall): *a*, specimen with arms; *b*, larger specimens without the arms. 319. Ichthyocrinus sublævis (after Hall).

Stemmed Echinoderms, or Crinoids, may be divided into three families, viz.: 1. *Crinids;* 2. *Cystids;* 3. *Blastids.* *Crinids* are the typical Crinoids, with branching arms, already illustrated from living exam-

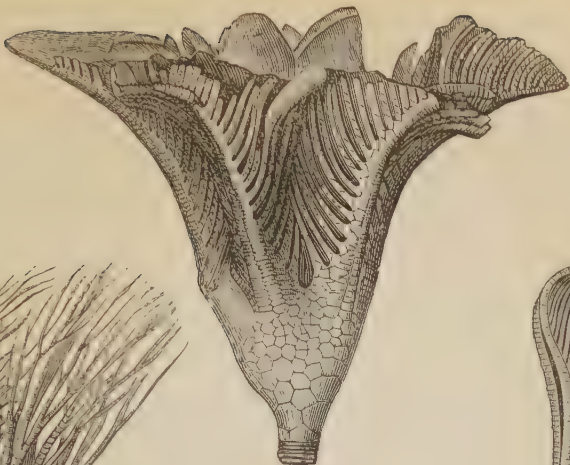


FIG. 320.

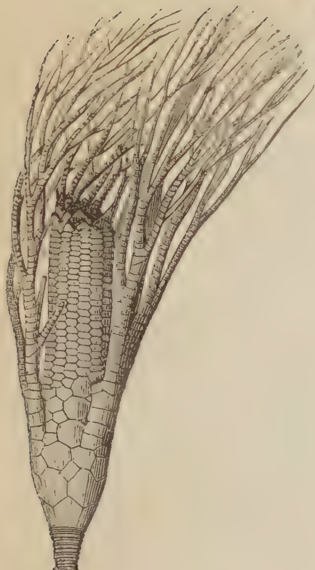


FIG. 321.

FIG. 322.

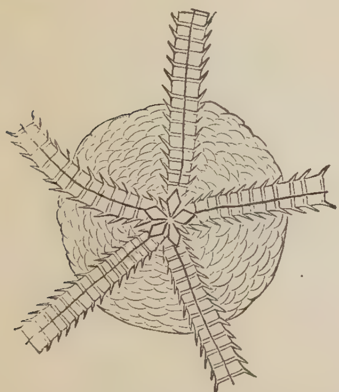


FIG. 323.

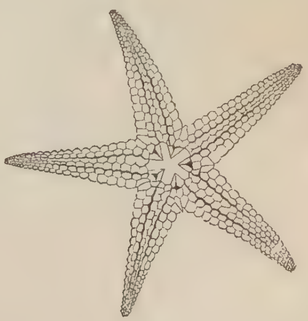


FIG. 324.

FIGS. 320–324.—SILURIAN CRINOIDS AND ASTEROIDS: 320. Mariacrinus nobilissimus (after Hall). 321. Homocrinus scoparius (after Hall). 322. Heterocrinus simplex (after Meek). 323. Protaster Sedgwickii. 324. Palæaster Shæfferi (after Hall).

ples (Figs. 310–312). *Cystids* are of a *bladder*-like form (hence the name), and are either without arms, or else have *few, short, simple* arms springing from near the centre of the upper part of the body, the mouth being probably on one side. The radiated structure in these is imperfect. *Blastids* (Gr. βλαστος, *a bud*) had a bud-shaped body, with five petalloid spaces (ambulacra) radiating from the top and reaching half-way down the body (*see* Figs. 514–517, p. 394). If Crinids are comparable to inverted Starfishes with many arms and set upon a stalk, the Cystids and Blastids may be compared to Sea-urchins similarly set. All these families are found in the Silurian. The Cystids pass away with the Silurian, and are therefore characteristic of that age. The Blastids pass away before the end of the Carboniferous age, and are therefore characteristic of the Palæozoic era. The Crinids continue, though in diminished numbers, to the present day. Figures of Blastids are given under the Carboniferous, where they were far more abundant.

Mollusks—*Acephals or Bivalves.*—Bivalves may be divided into two great sub-classes, viz., *Lamellibranchs* (leaf-gills) and *Brachiopods* (arm-feet). The valves of Lamellibranchs are *right and left;* those of Brachiopods are *upper and lower*, or dorsal and ventral. Brachiopods are much less highly organized than the other sub-class, and differ so essentially in their organization that some of the best naturalists remove them not only from the class of Acephals, but from the *department* of Mollusca, and ally them rather with the *Worms*. Their general resemblance in external form to bivalves makes it more convenient to treat them under that head, until the question of their affinity is more definitely settled.

Fig. 325. — Lingula anatina, showing the muscular peduncle by which the shell is attached.

General Description of a Brachiopod.—A Brachiopod shell consists of two valves, a dorsal and a ventral. The ventral is the larger, and usually projects beyond the dorsal, at the hinge, as a prominent beak. This projecting portion is often perforated to give passage to a muscular peduncle, by which the shell is attached in the living animal. The following figures (Figs. 325, 326) of Brachiopods, living and extinct, will make these points clear.

The viscera of a Brachiopod fill but a small space in the shell, this cavity being occupied principally by two long spiral arms (hence the name), which probably subserve the functions of respiration and alimentation. These arms are attached to a curious bony apparatus, sometimes itself spiral in form. Figs. 327–329 show the internal structure described above.

In the present seas the Lamellibranchs are extremely abundant,

FIG. 326.—Rhynchonella sulcata: side-view, dorsal view, and showing suture.

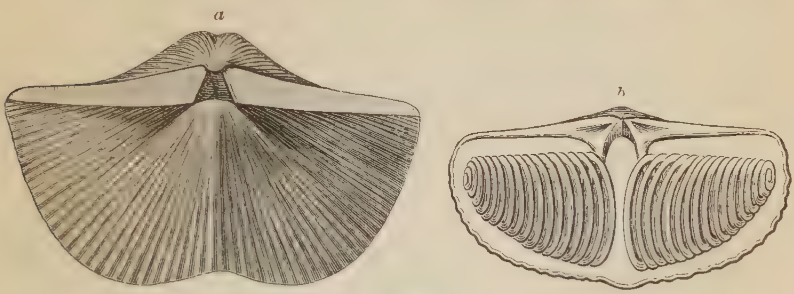


FIG. 327.

FIG. 328.

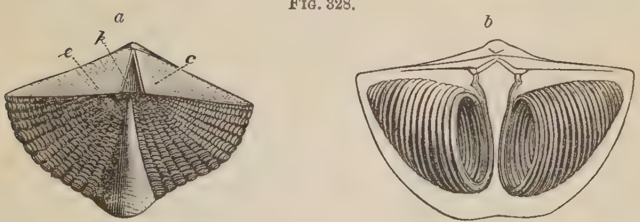


FIG. 329.

FIGS. 327-329.—SHOWING THE STRUCTURE OF BRACHIOPODS: 327. Spirifer striatus (Carboniferous): *a*, dorsal surface; *b*, interior, showing the bony spirals. 328. Terebratula flavescens (living species): *a*, exterior surface; *b*, showing bony structure for attachment of spiral arms. 329. Spirifer hysterica (Carboniferous): *a*, exterior; *b*, showing bony spires.

while the Brachiopods are nearly extinct, being represented by very few species. In Silurian times, on the contrary, the very reverse is the case, bivalve shells being represented mostly by Brachiopods. Taking the number of bivalve species throughout geological times as constant, then the general relation of these two sub-classes to each in time may be roughly represented by the following diagram, in which the lower

triangle represents Brachiopods, the upper Lamellibranchs, and the common diagonal the line of decrease of one and increase of the other.

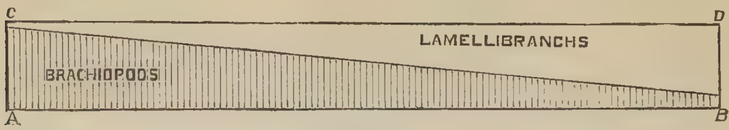


FIG. 330.—Diagram showing the General Alteration of Brachiopods to Lamellibranchs.

The abundance of individuals and the number of species of this order in Silurian times are almost incredible. The following figures represent some of the common and characteristic forms.

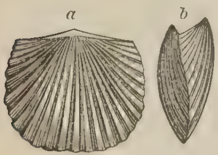


FIG. 331.

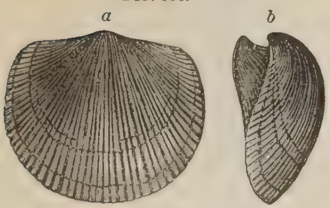


FIG. 332.

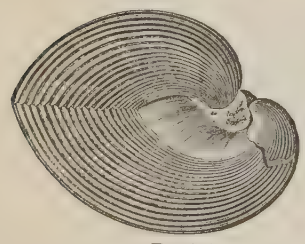


FIG. 334.

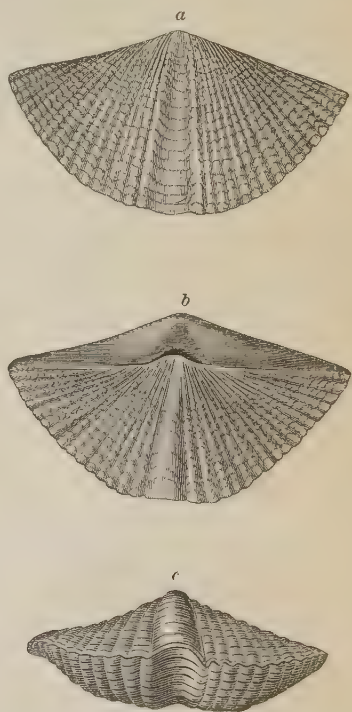


FIG. 333.

FIGS. 331–334.—SILURIAN BRACHIOPODS: 331. Orthis Davidsonii. 332. Orthis porcata. 333. Spirifer Cumberlandiæ: *a*, ventral valve; *b*, dorsal valve; *c*, suture. 334. Pentamerus Knightii.

It is very difficult to give any general distinctive mark of *Silurian* Brachiopods, although, of course, the species and even the genera are peculiar, and may be recognized by the paleontologist. It may be said, however, that the *straight-hinged* or *square-shouldered* Brachiopods, including the Spirifer family, the Strophomena or Leptena family, and

the Productus family, are characteristic of the Palæozoic, though not of the Silurian.

Lamellibranchs.—We have said that Lamellibranchs are also found in the Silurian, but not so abundantly as the Brachiopods. Lamellibranchs are divided into Siphonates and Asiphonates, i. e., those with

FIG. 335.

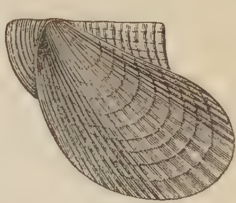


FIG. 336.

FIG. 337.

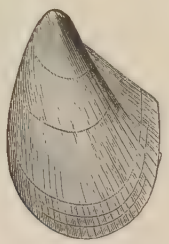


FIG. 338.

FIG. 339.

FIGS. 335–339.—SILURIAN LAMELLIBRANCHS: 335. Orthonota parallela. 336. Cardiola interrupta (after Hall). 337. Avicula Trentonensis (after Hall). 338. Ambonychia bellistriata (after Hall). 339. Tellenomya curta (after Hall).

and those without breathing-siphons behind. The Siphonates are the higher. At present the Siphonates are the more abundant—in Palæozoic times the Asiphonates. We give some figures above.

FIG. 340.

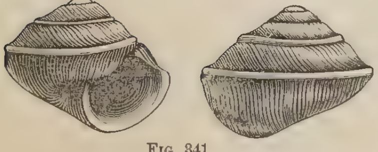


FIG. 341.

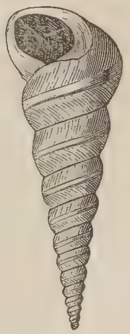


FIG. 342.

FIGS. 340–342.—SILURIAN GASTEROPODS: 340. Pleurotomaria dryope. 341. Pleurotomaria agave. 342. Murchisonia gracilis.

Gasteropods—*Univalves.*—*Land* and *fresh-water* Gasteropods have not been found in the Silurian. If we divide marine Gasteropods or univalves into those having beaked shells and those having smooth-mouthed or beakless shells, the former being carnivorous and the latter herbivorous, then only the smooth-mouthed or beakless shells have

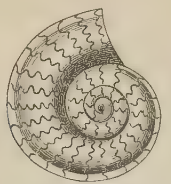


Fig. 343.

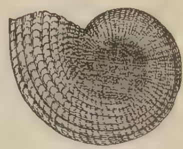


Fig. 345.

Fig. 344.

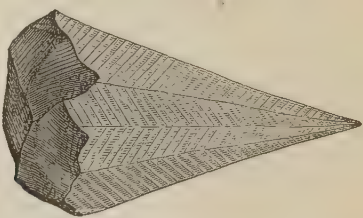


Fig. 346.

Figs. 343-346.—Silurian Gasteropods and Pteropods: 343 Cyrtolites compressus (after Hall). 344. Cyrtolites Trentonensis (after Hall). 345. Cyrtolites Dyeri (after Meek). 346. Conularia Trentonensis (after Hall), a Pteropod.

been found in the Silurian. The beaked-shelled are usually regarded as the more highly-organized class. The affinities of Conularia (Fig. 346) and Tentaculites are little understood. They are usually placed among Pteropods.

Cephalopods—*Chambered Shells.*—These are by far the most highly organized of Mollusks, and the most powerful among Invertebrates. They are represented in the present seas by the Nautilus, the Squids, and the Cuttle-fishes. If we divide all known Cephalopods into *Dibranchs* (two-gilled) and *Tetrabranchs* (four-gilled), the former being *naked* and the latter *shelled*, then, at the present time, the Dibranchs, or naked, vastly predominate, there being only a single genus of shelled or Tetrabranchs known, viz., the Nautilus, and of this genus only three or four species. In the Silurian age, and for many ages afterward, *only the shelled* existed. The naked or Dibranchs are decidedly the higher in organization.

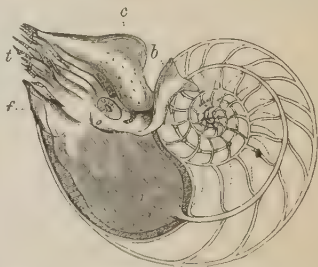
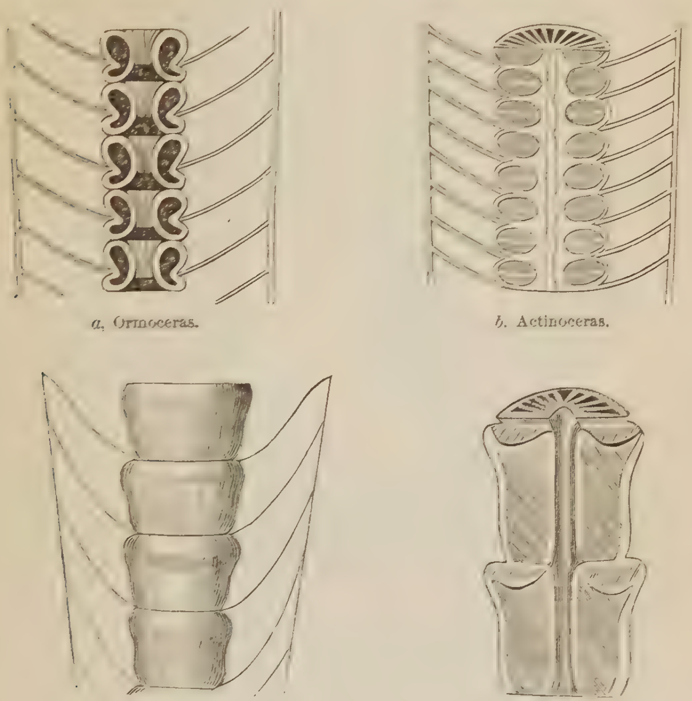


Fig. 347.—Pearly Nautilus (Nautilus pompilius): *a*, mantle; *b*, its dorsal fold; *c*, hood; *o*, eye; *t*, tentacles; *f*, funnel.

Again, if we divide chambered shells into those having *simple* septa and *central* or subcentral tube or siphon (*Nautilus tribe*), and those having septa plaited at their junction with the shell (plaited suture) and *dorsal* tube (*ammonite tribe*), then in the Silurian age the former only were represented.

Again, if we divide the *Nautilus tribe* into *straight*-shelled and *coiled*-shelled, then the straight-chambered shells greatly predominated. Straight-chambered shells are called Orthoceratites (ορθος, *straight;* κερας, *horn*). The Orthoceratites, therefore, are a very striking feature of the Silurian age. They may be defined as straight-chambered



a, Ormoceras. *b*, Actinoceras.

c, Huronia. *d*, Section of Siphuncle of Huronia.

FIG. 348.—*a*, *b*, *c*, *d*, Showing Structure of Orthoceratite.

shells, with simple partitions and a central or subcentral siphon-tube (siphuncle). The siphuncle of the family was large in proportion to the shell, and had often a beaded structure (Fig. 348, *a*, *b*, *c*, *d*). The genera are founded largely on the form of this part.

They existed in great numbers, and attained very great size. Specimens have been found fifteen feet long, and eight to ten inches in diameter. They were, without doubt, the most powerful animals of that

time, the tyrants and scavengers of these early seas. We give, in Fig. 357, a restoration of the creature. They are entirely characteristic of

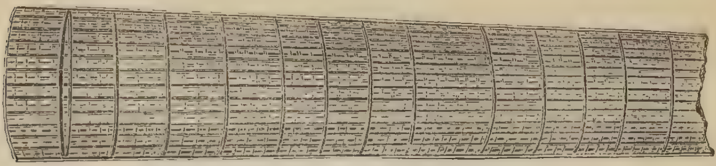


Fig. 349.

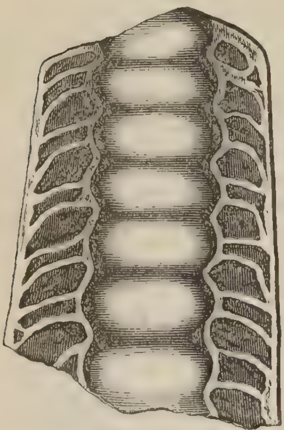


Fig. 350.

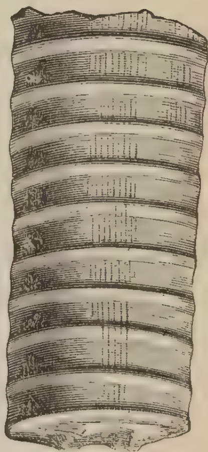


Fig. 351.

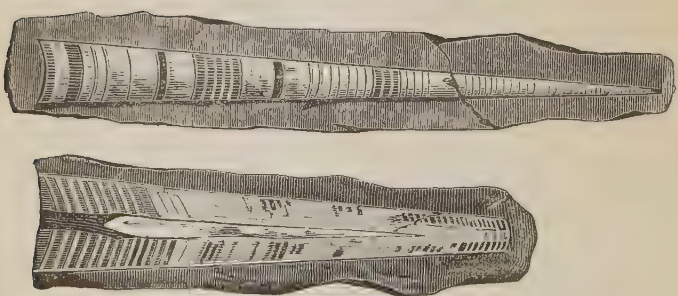


Fig. 352.

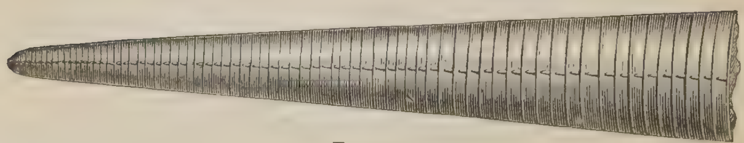


Fig. 353.

Figs. 349–353.—Silurian Cephalopods: 349. Orthoceras medullare (after Meck). 350. Ormoceras tenuifilum showing chambers and siphuncle (after Hall). 351. Orthoceras vertebrale (after Hall). 352. Orthoceras multicameratum (after Hall). 353. Orthoceras Duseri (after Hall).

the Palæozoic; commencing in the Primordial, extending through into the Carboniferous, and passing out there. They attained their maximum of development in size and number in the Silurian.

Although straight-chambered shells (Orthoceratites) are most abundant and characteristic, coiled shells of the same tribe are also found, and some of them of considerable size. Some of these are close-coiled

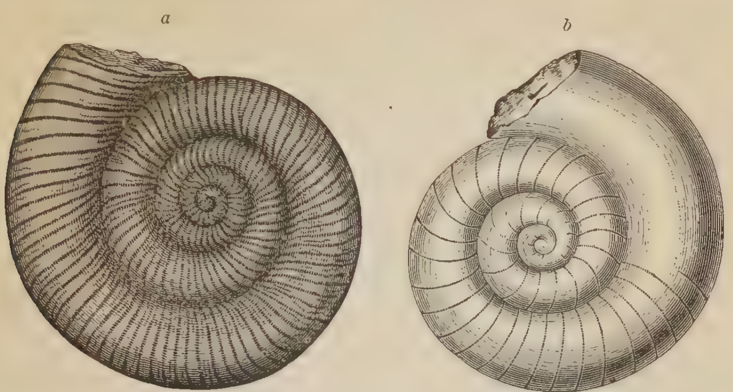


Fig. 354.

Fig. 355.

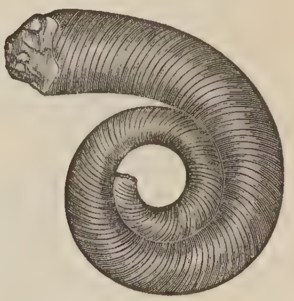


Fig. 356.

Figs. 354–356.—Silurian Cephalopods: 354. Trocholites Ammonius (after Hall): *a*, exterior; *b*, cast, showing septa. 355. Lituites Graftonensis (Meek and Worthen). 356. Lituites cornu-arietis.

shells, true Nautilus family; others open-coiled, and more nearly allied to the straight. Barrande gives 1,622 species of Cephalopods in the Silurian.

Articulates—*Worms.*—These are fleshy animals without skeletons, and are therefore not preserved. They are known only by their *tracks*, their *borings*, their tubes, and, more rarely, their teeth. Nevertheless, some 185 species, according to Barrande, have been described from

the Silurian of different countries. Fig. 358 represents worm-tubes, Fig. 359 worm-tracks, and Fig. 359a worm-teeth, from the Silurian.

Crustacea—*Trilobites.*—The principal representatives of the articulate department in Silurian times were *Crustaceans,* but mostly of a very characteristic order of that class, now long extinct, viz., *Trilobites.*

General Description.—The carapace or shell of these curious creatures was convex and usually smooth above, and flat or concave below, and divided transversely, like most crustacea, into a number of movable

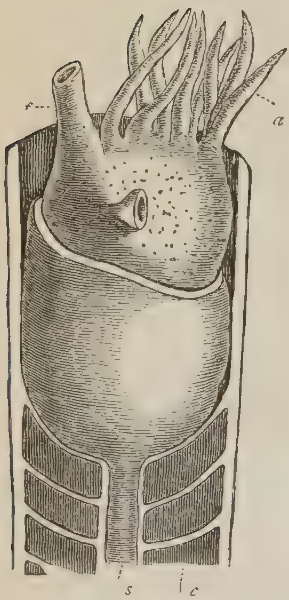


FIG. 357.—Restoration of Orthoceras, the shell being supposed to be divided vertically, and only its upper part being shown: *a*, arms; *f*, muscular tube ("funnel") by which water is expelled from the mantle-chamber; *c*, air-chambers, *s*, siphuncle (after Nicholson).

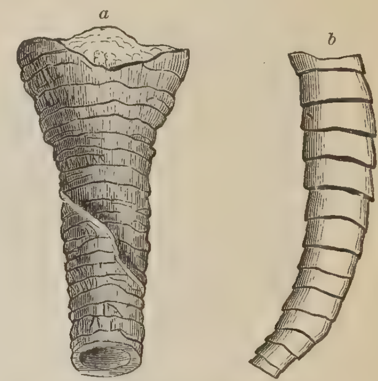


FIG. 358.

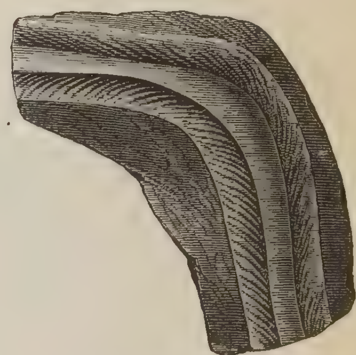


FIG. 359.

FIGS. 358, 359.—SILURIAN ANNELIDS: 358. Cornulites serpentarius (Worm-Tube). 359. Trail of an Annelid (after Hall).

joints. Several of the front joints are *always* consolidated to form a head-shield or *Buckler*, and *sometimes* a number of the posterior joints are similarly consolidated to form a tail-shield or Pygidium. The whole shell or carapace is divided longitudinally, more or less distinctly, into three lobes (hence the name)—a middle, a right, and a left. The viscera were contained in the middle lobe, the two side lobes

being extensions of the shell, as seen in the section, Fig. 360a. Well-organized compound eyes are distinctly seen in well-preserved specimens on the lateral lobes of the head-shields (cheeks) (Fig. 360). The under side of the animal has never been distinctly seen, and therefore the character of the locomotive organs is not certainly known. But it is believed that, like some of the lower Crustaceans of the present

FIG. 359a.—Worm-teeth from Cincinnati group, enlarged (after Hinde).

day (Phyllopods), their limbs were mostly thin, flat, soft, leaf-like swimmers. Walcott, however, has recently shown that, in addition to these (or perhaps instead of these), there were also slender-jointed legs and spiral organs which were probably gills, as shown in the section, Fig. 360a. On this view it is easy to see why the under side is never exposed; for the mud, in which they were entombed, would become entangled among these leaf-like swimmers, and in breaking the rock this would determine the line of fracture over the smooth back,

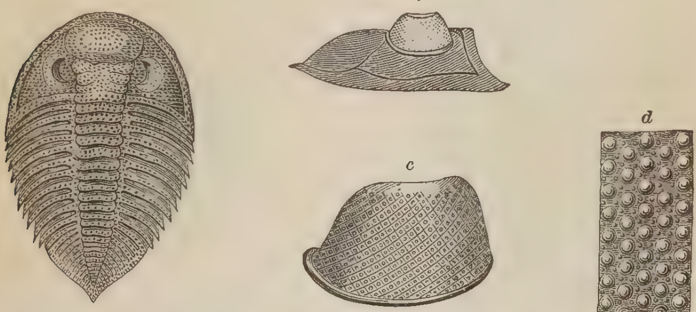


FIG. 360.—Structure of the Eye of Trilobites: *a*, Dalmania pleuropteryx; *b*, eye slightly magnified; *c*, eye more highly magnified; *d*, small portion still more highly magnified (after Hall).

and leave the creature firmly attached by its ventral surface to the lower piece. Not uncommonly Trilobites are found folded up on their ventral surface, so as to bring head and tail together and form a kind of ball. In such cases the Trilobite may be gotten out of the rocky matrix complete; but none the less are the feet completely hidden (Fig. 361a).

The great number of genera into which this large order is divided is founded principally on the form and sculpturing of the Buckler, the

size and form of the Pygidium, the number of the movable segments, etc. The figures below and on the next page will give an idea of some of these forms.

It is very interesting to observe that a complex mechanism, the compound eye like that of crustaceans and insects of the present day, was already developed even in the earliest Primordial times.

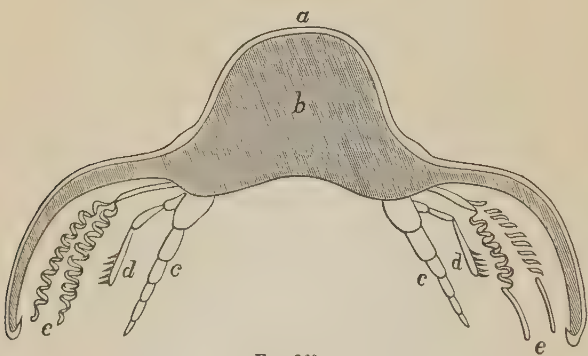


FIG. 360a.

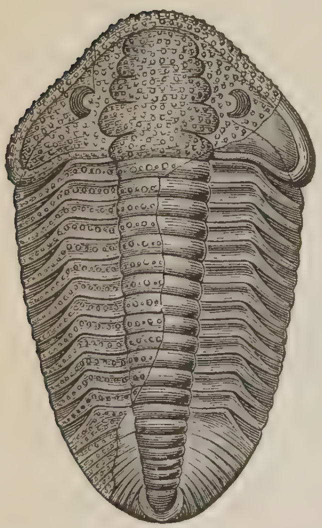


FIG. 361.

FIG. 361a.

FIGS. 360a-361a.—SILURIAN TRILOBITES: 360a. Transverse section of the thorax of Calymene senaria partially restored (after Wolcott). *a*, dorsal crust; *b*, visceral cavity; *c*, legs restored; *d*, epipodite; *e*, spiral gills; ×6. 361. Calymene Blumenbachii. 361a. Same in folded condition.

Trilobites commenced, as already stated, in the earliest Primordial, continued through the whole Palæozoic, and then became extinct forever. They are therefore entirely characteristic of the Palæozoic. They

reached their maximum of development, in size, number, and variety, in the Silurian. Barrande gives the number of species described in the Silurian alone as 1,579. They reached in some cases a size equal to any crustaceans now living. The *Asaphus* (*Isotelus*) *gigas*, from the Lower

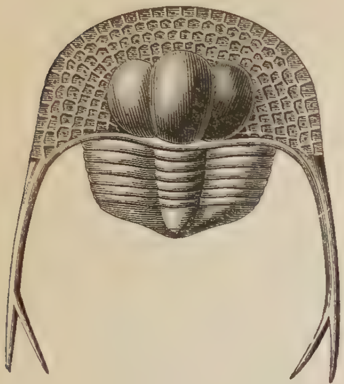


FIG. 362.

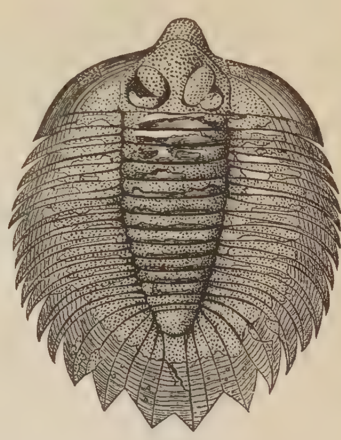


FIG. 363.

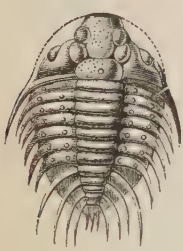


FIG. 364.

FIG. 365a.

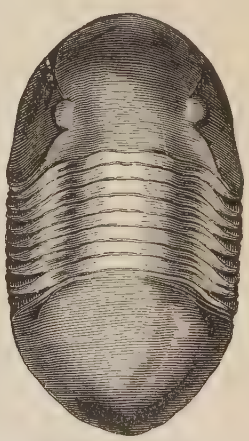


FIG. 365.

FIGS. 362–365a.—SILURIAN TRILOBITES: 362. Trinucleus Pongerardi. 363. Lichas Boltoni (after Hall). 364. Acidaspis crosotus (after Meek). 365. Isotelus gigas, reduced (after Hall). 365a. Same, side-view.

Silurian (Fig. 365), was sometimes twenty inches in length and thirteen wide. Parodoxides (Fig 280, p. 298), of the earliest Primordial, attained a length of twenty-two inches. On account of their great abundance and fine preservation, their embryonic development has been

carefully studied by Barrande, who has described and figured thirty steps in the development of some species. According to Agassiz, we know more of the development of trilobites than of any living crustacean.

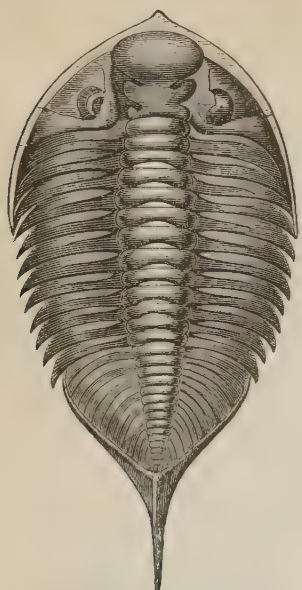


FIG. 366.—Dalmania limulurus.

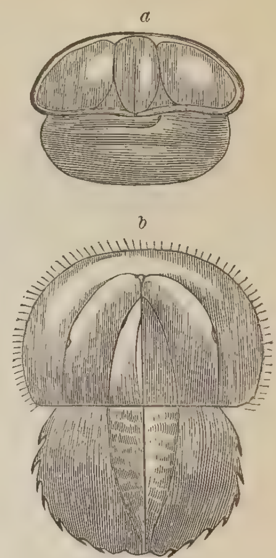


FIG. 367.—*a*, Larva of a Trilobite; *b*, Larva of a King-Crab (after Packard).

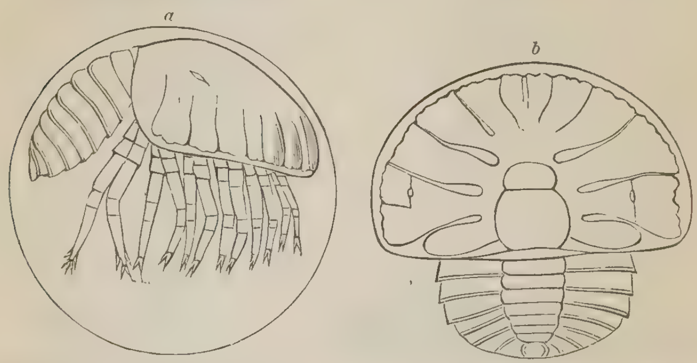


FIG. 368.—Limulus before hatching, Trilobite Stage: *a*, side view. Limulus before hatching, Trilobite Stage: *b*, dorsal view (after Packard).

Affinities of Trilobites.—The affinities of this very distinct order are imperfectly understood. Crustaceans are divided into two sub-classes, a higher, *Malacostraca* (mollusk-shelled or calcareous-shelled), and a lower, *Entomostraca* (insect-shelled). Now, Trilobites, though belonging to the lower division, or Entomostraca, occupy a position near the confines of the two divisions. More definitely, they probably stand between the

Isopods (tetradecapod Malacostracans), on the one hand, and the *Phyllopods* and *Limuloids* (Entomostracans), on the other. In general appearance they certainly approach Limuloids (horseshoe-crabs or king-crabs), and these seem to have replaced them in the process of evolution. They are by no means very low in the scale of crustaceans; their position being near the middle. The larvæ of Crustaceans, especially of Limuloids, greatly resemble some forms of Trilobites, and especially the larvæ of Trilobites. From the generalized forms represented by Figs. 367 and 368 have been probably differentiated, in one direction the more perfect Trilobites, and, in the other, the Limuloids.

FIG 370.

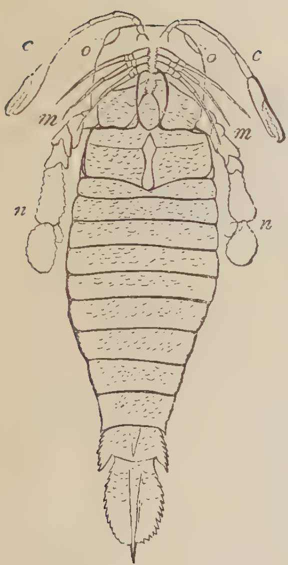


FIG. 369.

b a

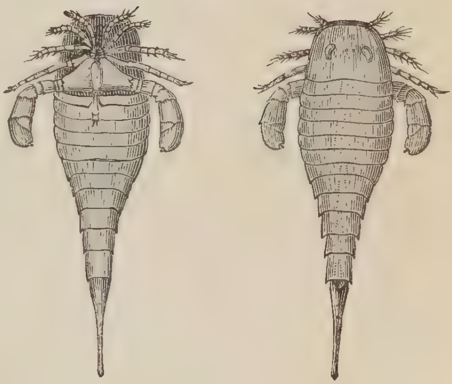


FIG. 371.

FIGS. 369–371.—SILURIAN EURYPTERIDS: 369. Pterygotus Anglicus, viewed from the under side, reduced in size, and restored: *c c*, the feelers (antennæ), terminating in nipping-claws; *o o*, eyes; *m m*, three pairs of jointed limbs, with pointed extremities; *n n*, swimming-paddles, the bases of which are spiny and act as jaws—Upper Silurian, Lanarkshire (after Henry Woodward). 370. Eurypterus remipes, greatly reduced. 371. Same restored: *a*, dorsal view; *b*, ventral view (after Hall).

Eurypterids.—In the Upper Silurian was introduced and continued to exist along with Trilobites during the rest of the Palæozoic, another family of huge entomostracans probably in advance of Trilobites in organization, viz., *Eurypterids*. The family includes the two genera

Eurypterus (broad wing) and *Pterygotus* (winged ear). Some of the latter are the largest crustaceans known. The huge *Inachus Koempferi* (Japan crab), with carapace sixteen inches in diameter, and legs four feet long, and the Moluccas king-crab (*Limulus Moluccanus*), three feet long and eighteen inches across the carapace, are the largest crustaceans now living. But the Eurypterids were some of them far greater. The *Pterygotus Anglicus* (Fig. 369) was six feet long and one foot wide, and the *Pterygotus Gigas*, seven feet long and proportionately wide. The above figures represent some species of these two genera from the American and English rocks.

Anticipations of the Next Age.—Animals and plants higher than those already mentioned can scarcely be said to belong to this age. Nevertheless, some anticipations of the next age may be briefly noted. A few very small land-plants (ferns and club-mosses) have been detected as early as the Middle Silurian, and a few small fishes, similar to those characterizing the Devonian, have been found in the uppermost beds of the Silurian, or passage-beds into the Devonian, in Europe, though not yet in America. Such anticipations are in accordance with the law already mentioned (p. 278), that the characteristics of an age often commence in the preceding age. It is better, however, to treat of these classes in connection with the age in which they culminate, or at least become a striking feature.

The Silurian was, therefore, essentially an age of Invertebrates. In number, size, and variety, these have scarcely been surpassed in any subsequent period. The most characteristic orders were: Among plants, Fucoids; among animals, Cyathophylloid and Tabulate corals, Graptolites, Cystidean crinoids, Square-shouldered brachiopods, Beakless gasteropods, Orthoceratites, and Trilobites. Orthoceratites and trilobites were the highest animals of the age, and the former were the rulers and scavengers of these early seas. We give below a table showing, according to Barrande, the number of Silurian species described up to 1872:

Sponges and other Protozoans	153	Brachiopods	1,567
Corals	718	Lamellibranchs	1,086
Echinoderms	588	Heteropods, Pteropods	390
Worms	185		
Trilobites	1,579	Gasteropods	1,306
Other Crustaceans	348	Cephalopods	1,622
Bryozoans	478	Fishes	40

Which, with four of uncertain relations, make 10,074 species.

Section 2.—Devonian System and Age of Fishes.

The name Devonian was given to these rocks by Murchison and Sedgwick, because in Devonshire the system occurs well developed,

and abounds in fossils. In England the system is usually unconformable with the underlying Silurian, and sometimes with the overlying Carboniferous, as in Fig. 372. But in the Eastern United States, as already stated, the Palæozoics are conformable throughout (Fig. 255).

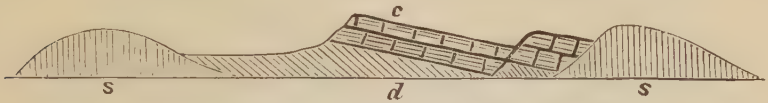


FIG. 372.—*s*, Silurian; *d*, Devonian; *c*, Carboniferous (after Phillips).

Area in United States.—The area over which the Devonian appears as a country rock is shown in map, page 289. It borders generally the Silurian on the south and southwest, extending with it far southward in the middle region, viz., in Indiana, Western Ohio and Kentucky. In the Basin Range region, especially about White Pine, Nevada, Devonian is known to exist, but the limits of these areas are too imperfectly known to be described.

Physical Geography.—In the eastern portion of the United States the land of the Devonian age was approximately that of the Silurian age already described, increased by the addition of the Silurian area, which Silurian was of course so much marginal sea-bottom exposed by upheaval during and at the end of Silurian times. At the end of Devonian times the Devonian area was added to the existing land, and the continental mass thus further increased.

Subdivision into Periods.—In the United States the following four periods are recognized by Dana:

4. Catskill period.
3. Chemung period.
2. Hamilton period.
1. Corniferous period.

We shall, however, neglect these subdivisions in our general description of the life of the age.

Life-System of Devonian Age—Plants.

It will be remembered that during the Silurian age, except a few small vascular cryptogams, the only plants found were Fucoids. These, of course, continued in Devonian times. But, in addition to these, were now introduced *land-plants* in considerable numbers and variety, and decided complexity of organization. They included all the orders of vascular cryptogams, viz., *Ferns*, *Lycopods*, and *Equisetæ;* and also *Conifers* among gymnospermous Phænogams; and by their great size and numbers probably formed for the first time in the history of the earth a true *forest vegetation.*

The Ferns were represented by several genera, such as Cyclopteris and Neuropteris; the Lycopods (club-mosses) not only by the Psilophy-

ton, which had been already introduced in the uppermost Silurian, but also now by gigantic *Lepidodendrids* and *Sigillarids*, and the Equisetæ by Calamites and Asterophyllites. The Conifers were represented

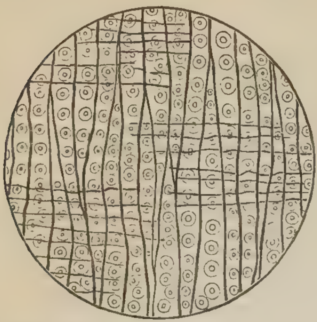


FIG. 373.—Microscopic Section of the Silicified Wood of a Conifer (*Sequoia*), cut in the long direction of the fibres. Post-tertiary ? Colorado. (After Nicholson.)

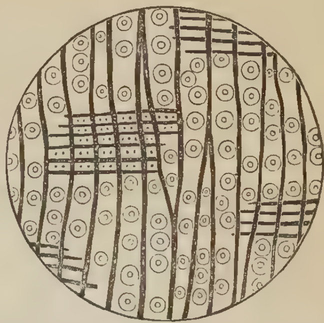


FIG. 374.—Microscopic Section of the Wood of the Common Larch (*Abies larix*), cut in the long direction of the fibres. In both the fresh and the fossil wood (Fig. 367) are seen the disks characteristic of coniferous wood. (After Nicholson.)

by the genus *Protaxites*, allied to the *yew* (Taxus). They are known to be conifers by their concentric rings of growth and gymnospermous tissue, i. e., the elliptic disk-like markings on the walls of the wood-cells on longitudinal section (Figs. 373 and 374), and the entire absence on *cross*-section of the visible pores so characteristic of dycolytedonous Exogens (Fig. 375). Some of these conifers have been found by Dawson eighteen inches, and one three feet, in diameter. There have been fifty species of land-plants of these various orders found by Dawson in the Devonian of Nova Scotia alone. On pages 329 and 330 we give the most characteristic Devonian land-plants.

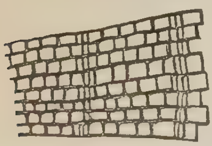


FIG. 375.—Pine-Wood, Cross-Section magnified.

General Remarks on Devonian Land-Plants.—We will not at present discuss the affinities of these plants, and their relations to evolution, because they are similar to those found in the *coal*, where they exist in far greater variety and abundance, and the subject will be discussed under that head. There are, however, some thoughts suggested by the first appearance of highly-organized plants which ought not to be omitted :

1. The ringed structure of Devonian conifers shows that, at that time, there was a growing season and a season of rest, and therefore, probably, a warm and a cold season. In one trunk the number of rings counted was 150, indicating a considerable age.

2. What were the precursors of this highly-organized forest vegetation ? That there *were* precursors, from which these were derived, there

can be little doubt, and we shall probably some day find them in the Upper Silurian; but that the *steps of evolution* were just at this point *somewhat rapid*, seems also certain. It is impossible to account for this comparatively sudden appearance of so highly-organized a vege-

Fig. 376. Fig. 379. Fig. 380.

Figs. 376–380.—Devonian Plants (after Dawson): 376. Psilophyton princeps, restored. 377. *a*, Lepidodendron Gaspianum; *b*, same enlarged. 378. *a*, Asterophillites latifolia; *b*, fruit of same. 379. Cyclopteris obtusa, a fern. 380. Neuropteris polymorpha, a fern.

tation by evolution, unless we admit that there have been periods of rapid evolution, as explained on page 299. When all the conditions are favorable for a great advance, the advance takes place at once, i. e., with great comparative rapidity.

3. We have seen that the coal vegetation is to a large extent anticipated in the Devonian. So, also, to some extent, were the conditions necessary to the preservation of this vegetation and the formation

of coal. In the Devonian, for the first time, we find dark bands between the strata, impregnated with carbonaceous matter. We find, also, thin seams of coal, with under-clays filled with ramifying rootlets, such as we shall find in the coal; in other words, we find ancient dirt-beds, sub-

Fig. 381.

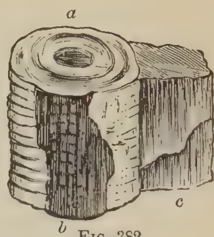


Fig. 382.

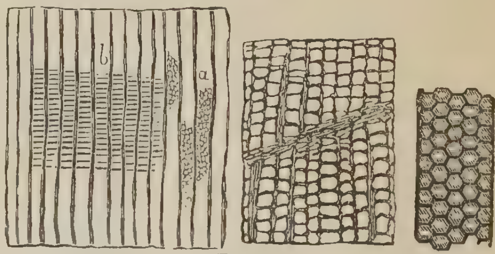


Fig. 383.

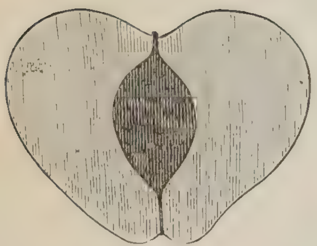


Fig. 384.

Fig. 385

Fig. 386.

Figs. 381–386.—Devonian Plants (after Dawson): 381. Cyclopteris Jacksoni, a Fern. 382. Dadoxylon Ouangondianum, a Conifer: *a*, Pith; *b*, Pith-Sheath; *c*, Wood. 383. Sections of same; *x*, Longitudinal; *y*, Transverse, enlarged—*z*, greatly magnified, showing disk-like markings. 384. Cardiocarpum Baileyi, a Fruit. 385. Anthophyllites Devonicus. 386. Cordaites Robbii, a Group of Leaves.

merged forest-grounds, and peat-bogs. All the phenomena of the coal-measures, therefore, are here found, though imperfectly developed, and the coal not workable. The Carboniferous day is already dawning.

Animals.

In accordance with our prescribed plan, all we can do in describing Devonian animals is to touch prominent points—to notice what is *going out*, *what is coming in*, and to dwell only on what bears on evolution.

FIG. 387.

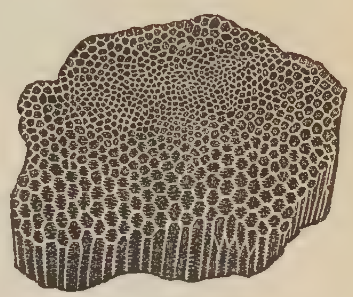


FIG. 388.

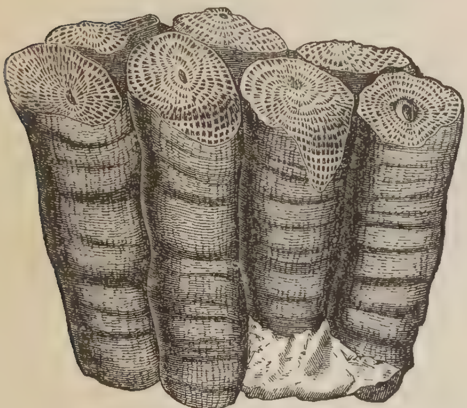


FIG. 389.

FIG. 390.

FIGS. 387-390.—DEVONIAN CORALS: 387. Acervularia Davidsoni (after Hall). 388. Favosites hemispherica. 389. Crepidophyllum Archiaci. 390. Zaphrentis Wortheni (after Meek).

Radiates.—Among corals, the chain-corals (*Halysitids*) have disappeared; the other orders continue under different species. Among hydrozoa, the *Graptolites* are gone; among Crinoids, the *Cystids* are gone, but in their place the *Blastids* (bud-like), those curious armless crinoids, with petalloid markings already spoken of as rare in the Silurian, become more abundant. The *Crinids*, or plumose-armed crinoids,

continue undiminished. The Blastids, however, are far more characteristic of the Carboniferous. We therefore defer their illustration to that period.

Brachiopods.—Brachiopods are still very abundant, and still many of them of the characteristic Palæozoic, square-shouldered type. Among spirifers, the long-winged species (Fig. 392) are very abundant and

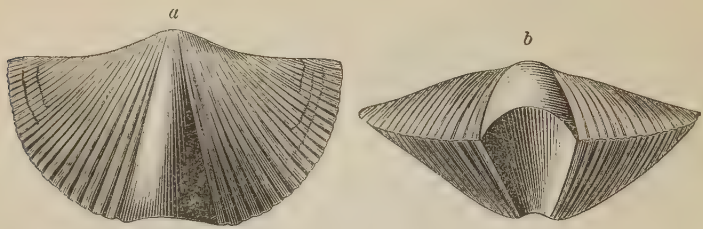


Fig. 391.

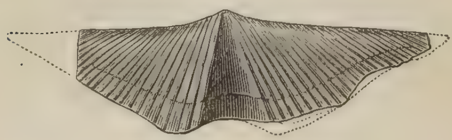


Fig. 392.

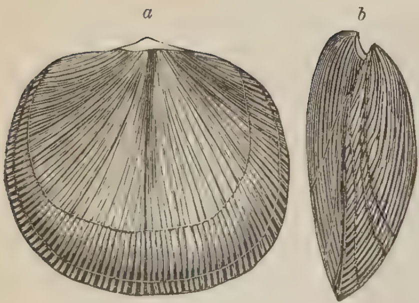


Fig. 393.

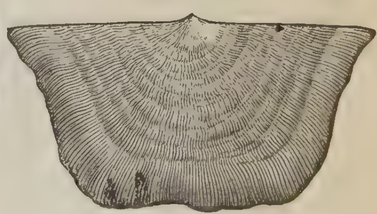


Fig. 394.

Figs. 391–394.—Devonian Brachiopods: 391. Spirifer fornacula (after Meek and Worthen): *a*, ventral valve; *b*, suture. 392. Spirifer perextensus (after Meek). 393. Orthis Livia: *a*, dorsal; *b*, side-view. 394. Strophomena rhomboidalis.

characteristic. We give a few figures of Devonian bivalves, both brachiopods and lamellibranchs, and a few univalves. It is worthy of remark that many of these univalves are fresh-water species.

Cephalopods.—The characteristic Palæozoic Cephalopods, or *Orthoceratites*, continue, but in greatly-diminished numbers and size; but the *Goniatites*, a coiled-chambered shell, which seems to be the *beginning of the Ammonite family*, are introduced first here. This family, as already explained, is distinguished by the complexity of the junction of

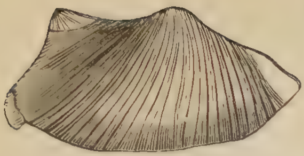
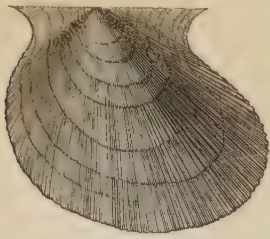




Fig. 398.

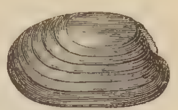


Fig. 395. Fig. 396. Fig. 397.

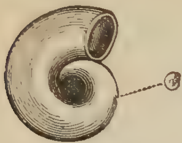
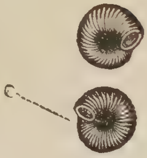



Fig. 399. Fig. 400.

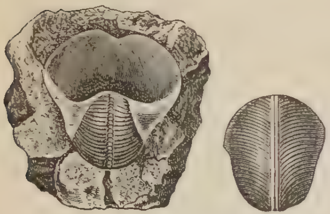



Fig. 402. Fig. 401.

Figs. 395-402.—Devonian Lamellibranchs and Gasteropods: 395. Conocardium trigonale (after Logan). 396. Aviculopecten parilis (after Meek). 397. Ctenopistha antiqua (after Meek). 398. Lucina Ohioensis (after Meek). 399. Spirorbis omphalodes, enlarged. 400. Spirorbis Arkanensis. 401. Orthonema Newberryi (after Meek). 402. Bellerophon Newberryi (after Meek).

the septa and the shell (*suture*), and by the dorsal position of the siphuncle. In the *Goniatites* the sutures are not yet very complex. They are only *zigzag*. This is shown in the figure.

Fig. 403.—Goniatites lamellosus (after Pictet).

Crustacea.—The very characteristic Palæozoic order *Trilobites* is still abundantly represented, although it has already passed its prime, and is diminishing in number and size of species. The *Eurypterids* introduced in the Upper Silurian maintain their place through the Devonian.

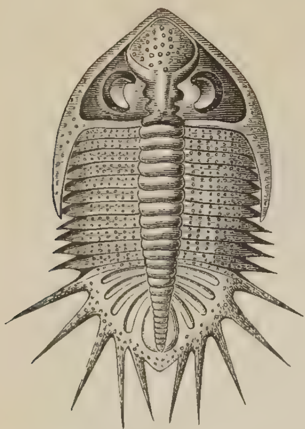


FIG. 404.

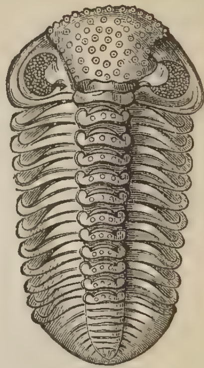


FIG. 405.

FIGS. 404 and 405.—DEVONIAN TRILOBITES: 404. Dalmania punctata, Europe. 405. Phacops latifrons, Europe.

Insects.—The earliest insects yet discovered are found in the Devonian of Nova Scotia. It is natural that insects should appear along with forest vegetation, and indeed the insects and the plants are found in the same strata.

The Devonian insects belong to the *Neuroptera* (nerve-wing), like the dragon-fly and ephemera, yet a chirping organ has been detected which allies them with the crickets, grasshoppers (*Orthoptera*), etc. They seem, therefore, to be a *connecting link between Neuropters and Orthopters.* An organ adapted to produce definite kinds of sound to attract their mates, of course, implies an organ adapted to appreciate sound. Evidently, therefore, the ear was already somewhat advanced in organization in these insects.

FIG. 406.—Wing of Platephemera antiqua. Devonian, America (after Dawson).

Fishes.—But the grand characteristic of the Devonian age is the *appearance* and *culmination* of the class of fishes. This is a great step in advance; for we have here the introduction, not only of a new class, but a new department (Vertebrata), and the highest of the animal kingdom. These earliest fishes, as might be expected, however, were far different from typical fishes of the present day. They belonged wholly

to the two orders *Ganoids* (gar-fish, sturgeons, and mud-fishes) and *Placoids* (sharks, skates, and rays), and to families of these orders which are now either wholly or nearly extinct. Appearing first in Uppermost Silurian and Lower Devonian, few in number and small in size, and of strangely-uncouth forms in Cephalaspis (Fig. 408) and Pteraspis (Fig. 407), the earliest-known genera, this class soon increased until the Devonian seas swarmed with them. Probably never in the history of the earth have fishes existed in greater numbers, variety, and size; and certainly never have they been more thoroughly armed for offense and defense. The Onychodus (claw-toothed—Fig. 417), in the Lower Devonian of the United States, had jaws eighteen inches long, and teeth two inches or more long. The animal itself is supposed to have been twelve to fifteen feet in length. The Dinichthys of Ohio had jaws twenty-two inches long, and the animal was eighteen feet long. The Asterolepis (star-scale), described by Hugh Miller, was still more gigantic, being probably twenty to thirty feet in length. The teeth of many of the Devonian Ganoids were decidedly reptilian in character, i. e., long, conical, and fluted at the base, as in many reptiles both living and extinct. The following figures represent some of the more characteristic Devonian fishes (*see* also on pages 336 and 337). Of Placoids, on account of their cartilaginous skeleton and absence of scales, only the teeth and spines are found. In some of the species these spines were eighteen inches in length.

Of the fishes above named, some have been so recently discovered, and so remarkable in character, that they seem to deserve more than a

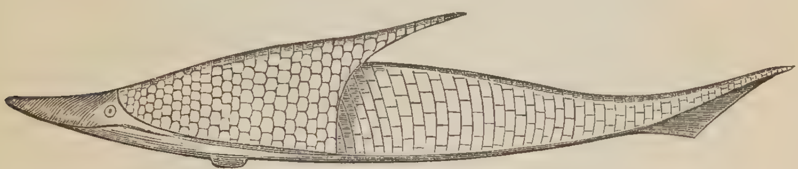


Fig. 407.

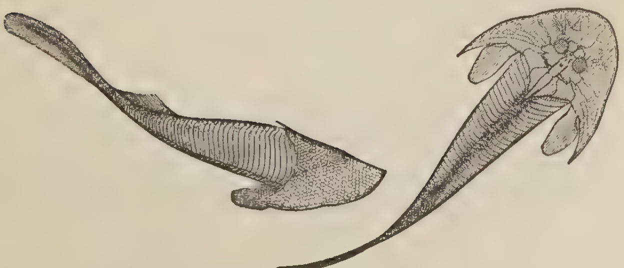


Fig. 408.

Figs. 407 and 408.—Devonian Fishes—*Placoderms:* 407. Pteraspis, restored by Powrie and Lankaster (after Dawson). 408. Cephalaspis Lyelli (after Nicholson).

bare mention. This is true especially of the Onychodus and the Dinichthys, recently discovered in the Devonian of Ohio, and described by Newberry.

The *Onychodus sigmoides* was a ganoid fish, twelve to fifteen feet

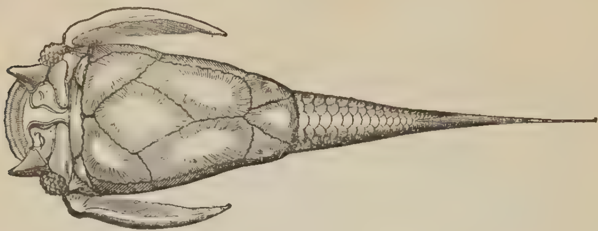


Fig. 409.

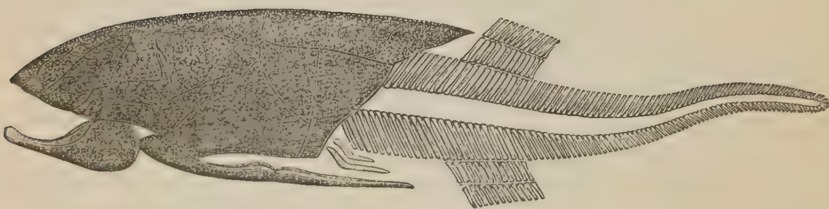


Fig. 410.

Fig. 411.

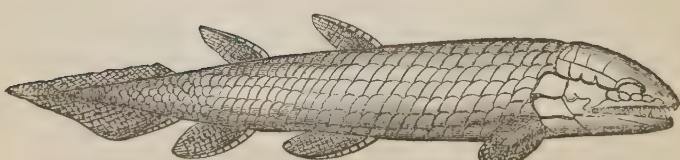


Fig. 412.

Figs. 409–412.—Devonian Fishes—*Placoderms:* 409. Pterichthys cornutus (after Nicholson). 410. Coccosteus decipiens (after Owen). *Lepidoganoids:* 411. Holoptychius nobilissimus (after Nicholson). 412. Osteolepis (after Nicholson).

in length, with lower jaw eighteen inches long, set with sharp, conical teeth, about three-fourths of an inch long, in the usual position. In addition to these, just at the chin-suture, were set a vertical row of pecul-

FIG. 413.

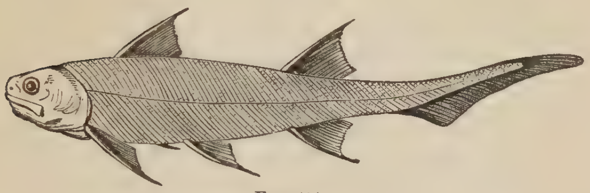


FIG. 414.

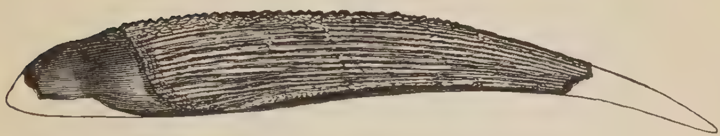


FIG. 415.

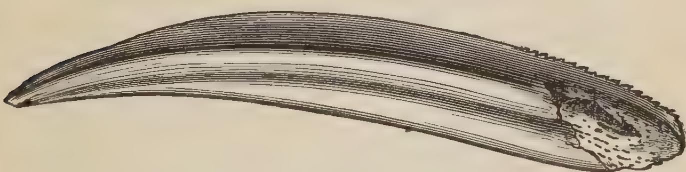


FIG. 416.

FIGS. 413–416.—DEVONIAN FISHES—*Lepidoganoids:* 413. Glyptolemus Kinairdii (after Nicholson). 414. Diplacanthus gracilis (after Nicholson). *Placoids:* 415. Ctenacanthus vetustus, Spine reduced (after Newberry). 416. Machæracanthus major, Spine reduced (after Newberry).

iarly-shaped teeth, at least two inches long, pointing forward (Fig. 417 *c*.) The body was covered with circular imbricated scales an inch in diameter (Fig. 417 *a*).

The *Dinichthys* is the hugest of Devonian fishes yet found in America, and second only to the Asterolepis of the European Devonian. According to Newberry, the body of this fish was fifteen to eighteen feet long and three feet thick. The jawbones, both upper and lower, are bent, the one downward, the other upward, at the extreme end, and extended to form two strong, sharp front teeth, above and below, while behind these the upper margin of the jaw is compressed into a sort of

knife-edged enameled bone, acting together like shear-blades, or in one species sharply dentate. The diagram Fig. 418 (in which, however, the bones are not in natural position) illustrates this structure. Newberry

FIG. 417.—Onychodus sigmoides (after Newberry): *a*, Scale, natural size; *b*, a Tooth, natural size; *c*, a Row of Front Teeth, reduced.

has drawn attention to the remarkable resemblance of this jaw-structure to that of the Devonian Coccosteus and the living Lepidosiren, the most reptilian of all known living fishes. This resemblance is shown in the accompanying figures (419 and 420).

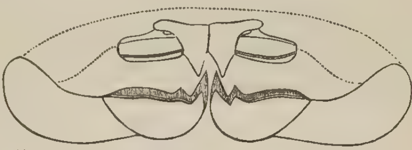


FIG. 418.—Jaws of Dinichthys Terrelli, × $\frac{1}{20}$ (after Newberry).

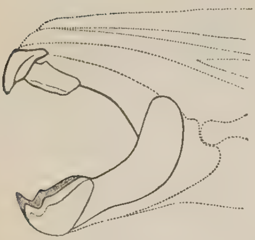


FIG. 419.—Jaws of Dinichthys (side-view, after Newberry).

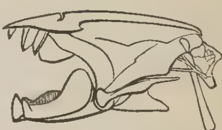


FIG. 420.—Jaws of Lepidosiren (side-view, after Newberry).

Like the Coccosteus (Fig. 410), not only the head but also the whole fore-part of the body of the Dinichthys, both above and below, was covered with large protecting plates. The want of scales in the hinder parts and the cartilaginous condition account for the fact that these parts have not yet been found.

Among other remarkable fishes found in the Devonian of Ohio may be mentioned Macropetalichthys (Fig. 421), several species of Coccosteus, and several of Acanthaspis—a genus allied to the Cephalaspis (Fig.

408). In the Devonian of New York, also, a number of species have been found.

Ganoids derive their name from the thick, bony, enameled scales which cover the body, forming an impenetrable coat-of-mail. Now, in the Devonian Ganoids, as seen in the figures, these scales were sometimes large and imbricated (Fig. 411), sometimes rhomboidal, arranged in oblique rows and nicely jointed, as in gar-fishes (*Lepidosteus* and *Polypterus*) of the present day (Figs. 412–414), and sometimes large, immovably soldered polygonal plates (Figs. 409, 410). Sometimes

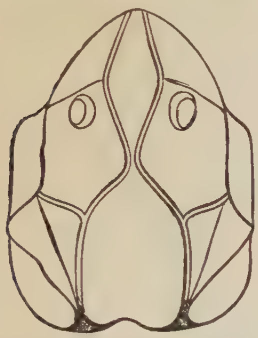


FIG. 421.—Skull of Macropetalichthys Sullivanti, reduced in size.

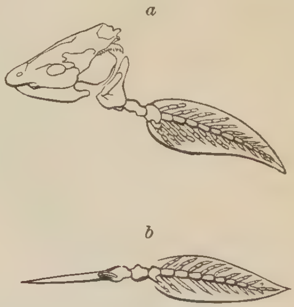


FIG. 422.—*a*, Head and fore limb of a Ceratodus; *b*, Hind limb of same (after Gunther).

the plates covered only the head (Cephalaspis), sometimes the head and forward portion of the body, and left the tail free for locomotion (Coccosteus); sometimes the whole body seems inclosed almost immovably in such plates, and the locomotion was effected in great part by arm-like fins (Pterichthys).

Most of the largest Devonian fishes, as the huge Asterolepis and the Dinichthys, belonged to the family of Plate-covered Ganoids. It is to this bony coat-of-mail that we are indebted for the fine preservation of Devonian Ganoids.

Affinities of Devonian Fishes.—Devonian Ganoids may be conveniently divided into two sub-orders, viz., *Lepido-ganoids* (Scale Ganoids), or Ganoids proper (Figs. 411–414), and *Placo-ganoids* (Plate Ganoids), or *Placoderms* (Figs. 407–410). The Placoderms are characteristic of the Devonian; the Lepido-ganoids continue in diminishing numbers even to the present time. The Placoderms have no living near congeners, although the Dinichthys, as just explained, has some affinities with the Lepidosirens. The nearest living allies of the Lepido-ganoids are the *Polypterus* of the Nile, the *Lepidosteus*, or Gar-fish, of North American rivers, the *Amia*, or mud-fish, of the same waters, the *Lepidosiren* of the African and South American

rivers, and the recently-discovered *Ceratodus* of Australian rivers,[1] a genus which ranged in time from the Triassic until now.

The Polypterus and the Ceratodus, especially the latter, have one very striking reptilian feature, viz., the paired-fins have a scaled lobe, supported by a many-jointed cartilaginous axis, running down the centre, and from which the rays come off on each side (Fig. 422). The

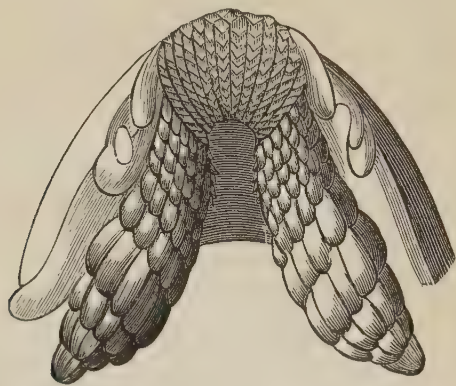


FIG. 423.—Dental Plate of Cestracion Phillippi.

paired-fins in these bear the same relation to the ordinary paired-fin of fishes which the vertebrated tail-fin does to the ordinary tail-fin (*see* next page). It is a true *scelidate*, or *legged* fin, and is connected, through the imperfect limb of the Lepidosiren, with true limbs of amphibians. Now, many of the Devonian fishes (Crossopterygians of Huxley) (Figs. 411 and 413) have this style of fin in a marked degree.

The living Placoid, which most resembles the Devonian Placoids, is the *Cestracion Phillippi* of Australia (Fig. 429). Instead of lancet-shaped teeth, which characterize most modern sharks, the jaws of the Cestracion are covered with a broad pavement of rounded plates, much like a pavement of cobble-stones (Fig. 423). The family of pavement-toothed sharks are called Cestracionts from this living representative. The Devonian Placoids were all, or nearly all, Cestracionts.

General Characteristics of Devonian Fishes.—Leaving out some small aberrant orders, fishes may be divided into three orders, viz., *Teleosts*, *Ganoids*, and *Placoids*. The Teleosts (perfect bone) comprise all the ordinary typical fishes. By far the larger number of living fishes belong to this order. The Ganoids are nearly extinct, but are still represented by the Polypterus, the Lepidosteus, the Amia, and the Sturgeon (Accipenser) ; and it is probable that we should include also the Dipnoi : i. e., Ceratodus, of the Australian rivers, and Lepidosiren, of African

[1] These last two genera are by many zoölogists put by themselves into a distinct order of fishes, the Dipnoi ; but they are undoubtedly very closely allied to the early Ganoids.

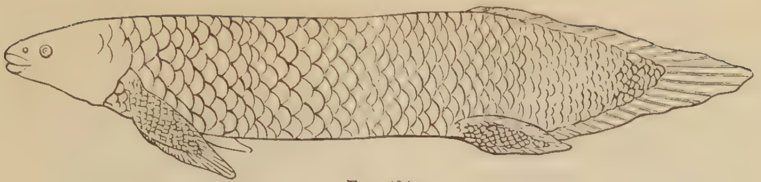


FIG. 424.

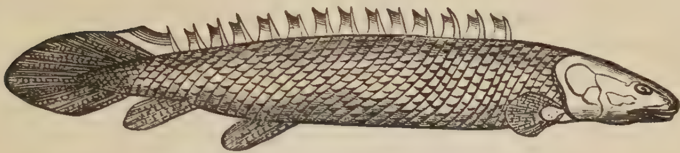


FIG. 425.

FIG. 426.

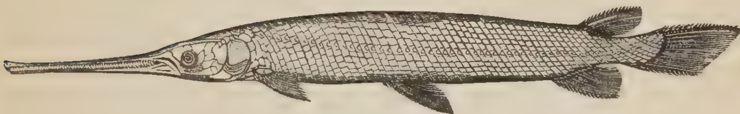


FIG. 427.

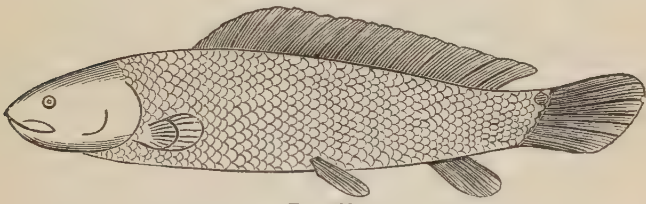


FIG. 428.

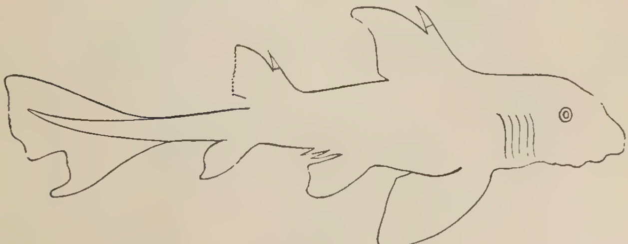


FIG. 429.

FIGS. 424–429.—NEAREST LIVING ALLIES OF DEVONIAN FISHES: 424. Ceratodus Fosterii, × $\frac{1}{12}$ (after Gunther). 425. Polypterus. 426. Lepidosiren. 427. Lepidosteus (Gar-Fish). 428. Amia (American Mud-fish). 429. Cestracion Phillippi (a Living Cestraciont from Australia).

and South American rivers. The Placoids (sharks and skates, etc.) are still abundant, but far less so than the Teleosts.

Now, as already said: 1. The *Devonian fishes were all Ganoids and Placoids*, especially the former. There were no ordinary typical fishes (Teleosts) at all at that time. 2. The Ganoids of the present day have, some of them, bony skeletons (Lepidosteus), and some cartilaginous skeletons (Sturgeon); the Devonian Ganoids all had more or less cartilaginous skeletons. Therefore, since all Placoids have cartilaginous skeletons, *all the fishes of these early times had cartilaginous skeletons.* 3. Of Ganoids of the present day, some have the mouth at the end of the snout (gar-pike), some beneath or on the ventral surface (sturgeons).

FIG. 430.—*a*, Homocercal; *b*, Heterocercal.

The same was true in Devonian times. The Lepido-ganoids had terminal mouth; the Placoderms, ventral mouth; and, since Placoids all have ventral mouth, *all the Devonian fishes, except the Lepido-ganoids, had the mouth on the ventral surface.* 4. There are two types of fish tail-fins, differing both in shape and structure. These are the *homocercal* (even-lobed), found in Teleosts (Fig. 430 *a*); and the *heterocercal* (uneven-lobed), found in Placoids (Fig. 430 *b*). In the homocercal, or even-lobed, the vertebral column terminates abruptly in one or several large flat bones, from which diverge the fin-rays (Fig. 431 *a*). In the heterocercal, or uneven-lobed, the vertical column runs to the extreme point usually of the upper lobe (Fig. 431 *b*). Such a tail-fin, therefore,

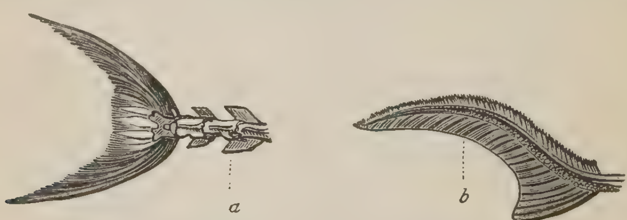


FIG. 431.—*a*, Homocercal (Sword-fish); *b*, Heterocercal (Sturgeon).

is said to be *vertebrated;* and this is the better name for this style of tail, as the structure is more important than shape, and in some cases a vertebrated tail may be nearly or quite symmetrical, as in Polypterus (Fig. 425), and Glyptolemus (Fig. 413). Now, while the tails of living Ganoids are some decidedly vertebrated, and some only slightly so,

those of *Devonian Ganoids* are all *decidedly vertebrated.* And since Placoids are all vertebrated-tailed, *all Devonian fishes are vertebrated-tailed.* To these characteristics may be added—5. Devonian Placoids were all *Cestracionts.* 6. Many Devonian Ganoids were *legged-finned.*

Rank of Devonian Fishes.—We have called Teleosts *typical* fishes. In Ganoids and Placoids, especially the former, and still more especially in the Devonian Ganoids, combined with their distinctive fish-characters, there are other characters which *ally them with reptiles*, and also still others which may be termed *embryonic.* The most important reptilian characters of Ganoids, especially Devonian Ganoids, are: 1. An *external armor* of thick bony plates or scales. 2. Large, conical teeth, with channeled base (Fig. 432 *a*), and labyrinthine internal structure, as shown in section (Fig. 432 *b*). Sometimes this structure is more complex than here represented. 3. A somewhat cellular swim-bladder, in some cases freely supplied with blood, opening by a tube into the pharynx, and therefore showing much analogy to, and in some cases (Ceratodus) acting as, an imperfect lung. We do not know that this was true of the Devonian Ganoids, but it is true of their nearest living allies, viz., Polypterus, Lepidosteus, Amia, and Ceratodus. 4. In many cases, paired fins which were jointed.

Fig. 432.—Structure of a Ganoid Tooth (after Agassiz).

Combined with these decidedly *reptilian* characters are others which are as decidedly *embryonic.* The most conspicuous of these are: 1. The *cartilaginous condition of the skeleton*, and even the retention of the embryonic fibrous chorda dorsalis, imperfectly articulated into a vertebrate column; and, 2. In the Placoderms, the *ventral position of the mouth.* The vertebrated tail-fin is regarded by some as embryonic, and by others as reptilian. It is doubtless both.

In Placoids there is a similar combination of reptilian and embryonic characters, except in this case the embryonic seem to predominate. These are, as before—1. The cartilaginous skeleton; 2. The inferior position of the mouth. But also, in addition, 3. The leathery or imperfectly rayed fins; 4. The want of an opercle or gill-cover, growing backward over, and thus covering the gill-slits; 5. Perhaps the ligamentous instead of bony attachment of the teeth.

On the other hand, the Placoids of the present day at least possess very high reptilian characters in their reproduction. In all Placoids their impregnation is internal, and instead of laying great numbers of unimpregnated ovules, like most Teleosts, they either lay few large, well-covered eggs like reptiles and birds (skates and some sharks), or else their eggs hatch within and they bring forth young alive (*ovo-viviparous*) like some reptiles; or in some cases there is even an attachment between the yolk-sac of the internally hatched young and the

oviduct of the mother, somewhat similar to that of the placenta to the uterus of the mammal. The young of Placoids also at first have a kind of external branchiæ like those of amphibian reptiles.

The following schedule shows the combination of characters enumerated. It is seen that in Ganoids the reptilian characters, in Placoids the embryonic characters, predominate. But, on the other hand, the

Ganoids.		Placoids.	
Reptilian	armor	reproduction	Reptilian
	teeth	tail-fin	
	swim-bladder	skeleton	Embryonic
	paired-fins	mouth	
	tail fin	fins	
Embryonic	skeleton	gills	
	mouth	teeth	

reptilian characters of Placoids are more decided and higher. The Lepido-ganoids of Devonian and Carboniferous times were far more reptilian than existing Ganoids; hence these have been appropriately called *Sauroid* fishes.

Bearing of these Facts on the Question of Evolution.—On account of this combination of *connecting* and *embryonic* characters—of characters which seem higher and others which seem lower than those of typical fishes—there has been much dispute as to the rank of Ganoids and Placoids, and especially of Devonian fishes, and therefore as to their bearing on the question of evolution. The dispute, however, has been mostly the result of a misconception of the true nature of evolution. The most fundamental law of evolution is *differentiation;* i. e., is a separation of one generalized form into several specialized forms—a separation of one stem into several branches. The Devonian fishes are an admirable illustration of this law. The first introduced fishes were not typical fishes, but *Sauroids*, i. e., fishes which combined with their distinctive fish-characters others which allied them with reptiles. They were the representatives and progenitors of both classes; from this common stem diverged two branches, viz., *typical fishes* on the one hand, and *reptiles* on the other. This is but one example of a very general law, which may be formulated thus: The first introduced of any class or order were not typical representatives of that class or order, but connecting links with other classes or orders, the complete separation of the two or more classes or orders represented being the result of subsequent evolution. Such connecting links are variously called *connecting types*, *synthetic types*, *comprehensive types*, *combining types*, *generalized types*, etc. We shall find many examples of such in the course of the history of the organic kingdom.

Suddenness of Appearance.—But it is impossible to overlook the

comparative suddenness of the appearance of a new class—fishes—and a new department—vertebrates—of the animal kingdom. Observe that at the horizon of appearance in the uppermost Silurian there is no apparent break in the strata, and therefore no evidence of lost record: and yet the advance is immense. It is impossible to account for this unless we admit paroxysms of more rapid movement of evolution—unless we admit that, when conditions are favorable and the time is ripe for a particular change, it takes place with exceptional rapidity, perhaps in a few generations.

Reptiles have not yet been found in the Devonian; Fishes therefore were the highest and most powerful animals then living. They were the rulers of the Devonian seas. The previous rulers, therefore, viz., Orthoceratites and Trilobites, according to a necessary law, in the struggle for life, diminish in size and number, and seek safety in a subordinate position.

Section 3.—Carboniferous System.—Age of Acrogens and Amphibians.

Retrospect.—Before taking up in detail this important and interesting age, it will be instructive to glance back over the ground traversed, and draw some conclusions.

If we compare, in physical geography, the American with the European Continent, we find the one marked by *simplicity* and the other by *complexity* of structure. This is true not only of the map-outline, but also of the profile-outline, or orographic structure. Now, as history furnishes the key to social and political structure, so *geology* furnishes the key to physical structure. The American Continent—at least in its eastern part—has developed comparatively *steadily* from the Laurentian nucleus southward and eastward, and probably northward. We have already seen how the Silurian area was added to the Laurentian, and the Devonian to the Silurian. It shall be our pleasure, hereafter, to show the continuance of this steady development throughout the whole geological history. For our knowledge on this interesting subject we are indebted almost wholly to Prof. Dana.

In the case of America, the continent thus sketched in outline in the earliest times has been steadily worked out in detail throughout all subsequent time; with some very considerable oscillations, true, determining unconformability of strata, rapid changes of physical geography and climate, and therefore of species, thus marking the great divisions of time, but on the whole without change of plan or wavering of purpose; in the case of Europe, on the contrary, geological history consists of a series of oscillations so great that it amounts to a successive making and unmaking of the continent.

Hence, nearly all geological problems are expressed in simpler terms, and are more easily solved here than there. Hence, also, while in Europe the ages and periods are separated by unconformability of the rock-system, as well as change in the life-system, in America they are separated mainly by change in the life-system only.

Subdivisions of the Carboniferous System and Age.—The Carboniferous age is subdivided into three periods, viz. : 1. Sub-Carboniferous; 2. Coal-measures, or Carboniferous proper; 3. Permian.

The sub-Carboniferous was the period of *preparation*; the Coal-measures the period of *culmination;* the Permian the period of decline and *transition* to the Mesozoic. The whole thickness of the carboniferous strata in Nova Scotia is 14,570 feet; in South Wales it is 14,000 feet, and in Pennsylvania 9,000 feet.

The sub-Carboniferous consists mainly of marine formations; the Coal-measures mainly of fresh-water formation—the former mainly of limestone, the latter mainly of sands and clays; the fossils of the former are, therefore, mainly marine animals, of the latter mainly fresh-water and land animals and plants, though marine animals are also found. In both Europe and America the coal-basins consisting of the latter are underlaid by the former, which, moreover, outcrop all around, forming a penumbral margin to the dark areas representing coal-basins on geological maps (*see* map, page 289). Between these two, or, rather, forming the lowest member of the Coal-measures, there is, in many places, a thick, coarse sandstone, called the *millstone grit.*

After this general contrast, we will now concentrate nearly our whole attention upon the Carboniferous period proper; because in this middle period culminated all the more striking characteristics of the age. In speaking of the life-system, however, we will draw from both sub-Carboniferous and Carboniferous indifferently. The Permian we shall treat only as a transition to the next *era.*

Carboniferous Proper—Rock-System or Coal-Measures.

The Name.—The Carboniferous period is but one of the three periods of this age. The Carboniferous age is, again, but one of the three ages of the Palæozoic era, while the Palæozoic era is itself but one of the four great eras, exclusive of the present, of the whole recorded history of the earth. The Carboniferous period, therefore, is probably not more than one-thirtieth part of that recorded history. Yet, during that period were accumulated, and in the strata of that period (Coal-measures) are still inclosed, at least nine-tenths of all the *worked* coal, and *probably nearly nine-tenths of all the workable coal in the world.* It is essentially the *coal-bearing period.* When we remember that every geological period has its characteristic fossils, by means of which the formation may be at once recognized by the experienced eye, it is easy

to see the importance of this simple fact as a guide to the prospector. It has been estimated that the money, time, and energy, uselessly expended in the State of New York in explorations for coal, where any geologist might be sure there was no coal, would suffice to make a complete geological survey of the State several times over! The same is true of Great Britain and many other countries.

Thickness of Strata.—Although constituting so small a portion of the whole stratified crust of the earth, the coal-measures are in some places of enormous thickness. In Nova Scotia they are 13,000 feet; in South Wales, 12,000 feet; in Pennsylvania, 4,000 feet; in West Virginia, over 4,500 feet.

Mode of Occurrence of Coal.—Such being the thickness of the coal-measures, it is evident that but a small proportion consists of coal. The coal-measures consist, in fact, of thick strata of sandstone, shales, and limestone, like other formations; but in addition to these are interstratified thin seams of *coal* and beds of *iron-ore.* Even in the richest coal-measures, the proportion of coal to rock is not more than as 1 to 50, and the proportion of iron is still much smaller. In some coal-fields, as, for example, in the Appalachian, *mechanical* sediments, shales, and sand-stones, predominate; in others, as in the Western coal-fields, *organic* sediments or limestone predominate.

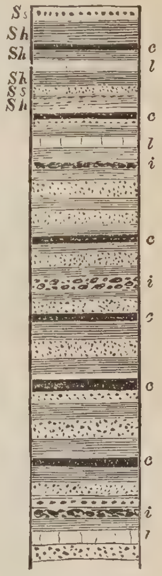


FIG. 433.—Ideal Section, showing Alternation of Different Kinds of Strata *Ss*, Sandstone; *Sh*, Shale; *l*, Limestone; *i*, Iron; and *c*, Coal.

The five kinds of strata mentioned are repeated in the same coal-basin very many times—perhaps 100 or more, as in the accompanying section; but, in comparing one coal-field with another, or in the same coal-field, in comparing one portion of the series with another, there is *no regular order of succession* discoverable. Except that immediately in contact with the seam beneath, there is nearly always a thin seam of *fine fire-clay.* This constant attendant of a coal-seam is called the *under-clay.* Again, immediately above, and therefore forming the roof of the opened seam, there is frequently, though not so constantly, a shale which, being impregnated with carbonaceous matter, is called the *black shale* or *black slate.* These accompaniments are, however, usually too thin to appear on sections.

In different portions, however, of the same coal-field, at the same geological horizon, we are apt to find the *same order.* This is the necessary result of the continuity of the strata over the whole basin. If we represent coal-basins, with their five different kinds of strata, by reams of variously-colored paper, then, while the order of succession may be different in the different reams, and

in the upper or lower portion of the same ream, yet at the same level we find the same order in every portion of the same ream. This is a test of a field even when separated by denudation into several basins. It is also a mode of identifying individual coal-seams; for, if the strata be continuous, then the seam will have the same accompanying strata above and below. The great Pittsburg seam has been thus identified, with great probability, over an area of 14,000 square miles, and, allowing for removal by denudation, over an original area of 34,000 square miles. Rogers thinks the original area may have been 90,000 square miles.[1] This rule for the identification of coal-seams of known value is often of practical importance; but it must be remembered that the strata of coal-measures, both the seams and the accompanying shale and sandstones, like all other strata, thin out on their edges (p. 173). Nevertheless, there is a most extraordinary continuity in the strata of the coal-measures.

Plication and Denudation.—Coal-bearing strata, like all other strata,

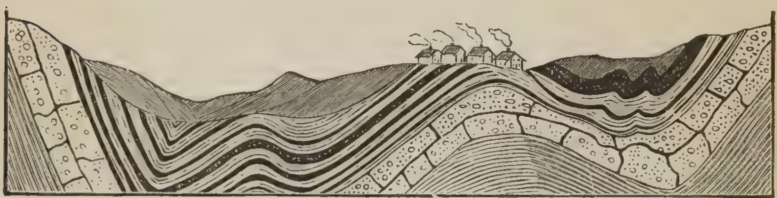


Fig. 434.—Panther Creek and Summit Hill Traverse (after Daddow).

were, of course, originally horizontal (p. 173) and continuous, but, like other strata, they are now found sometimes horizontal and some-

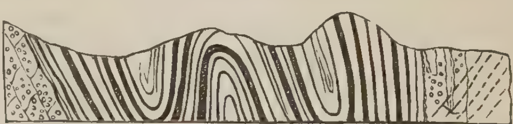


Fig. 435.—Nesquehoning Basins (after Daddow).

times dipping at all angles, and folded in the most complex manner. In the Appalachian region, especially in the anthracite region of Northern

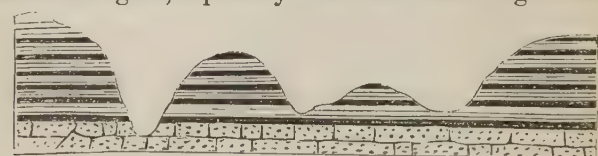


Fig. 436.—Illinois Coal-Field (after Daddow).

Pennsylvania, the strata are very much disturbed, and the coal-seams interstratified with them are often nearly perpendicular (Figs. 435 and 437),

[1] Phillips, "Geology," p. 217.

while in Indiana and Iowa the coal-strata are nearly or quite horizontal (Fig. 436). But, whether horizontal, or gently folded, or strongly pli-

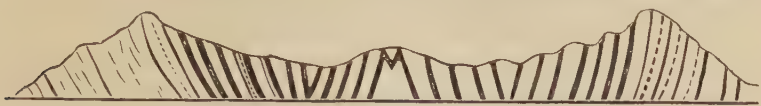


Fig. 437.—Section near Nesquehoning (after Taylor).

cated, in all cases denudation has carried away much of the upper portions, leaving them in isolated patches as mountains or basins, as shown in the map of Northern Pennsylvania (Fig. 439) and in the section (Fig. 438).

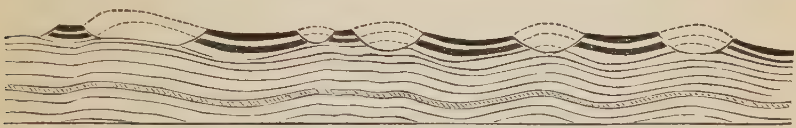


Fig. 438.—Section of Appalachian Coal-Field, Pennsylvania, showing Effects of Erosion on Gently-Undulating Strata (after Lesley).

By means of the rule for identifying seams given above, it is often easy to trace the same seam from one basin to another, or from one mountain-side to another, with great certainty.

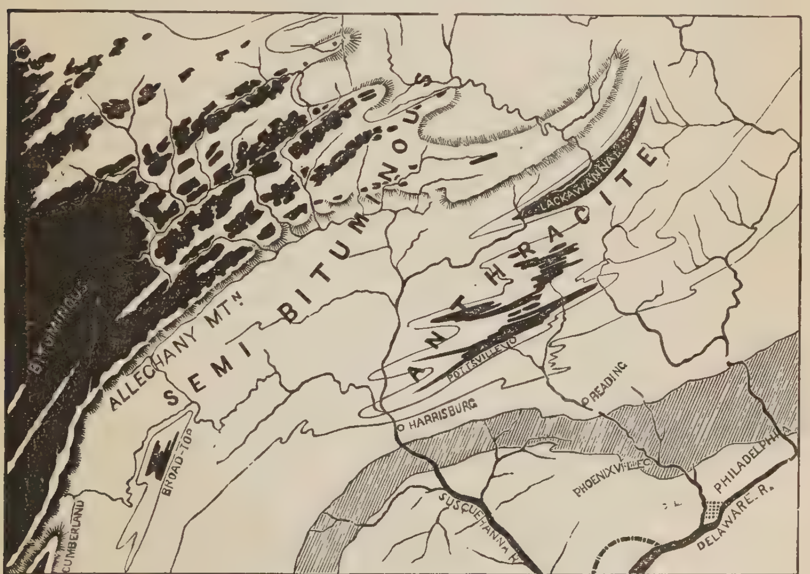


Fig. 439.—Map of Anthracite Region of Pennsylvania (after Lesley).

Faults.—It is plain, from what has been said above, that there is an essential difference between a coal-*seam* and a metalliferous *vein*.

Coal-seams are conformable with the strata, and are therefore *worked wholly between the strata.* This would be a comparatively easy matter if it were not for slips or faults which often occur, and sometimes make the working unprofitable. In case of a fault, it is important to remember the rule already given on page 233, viz., that most commonly the strata on the foot-wall side of the fissure goes upward. In the following

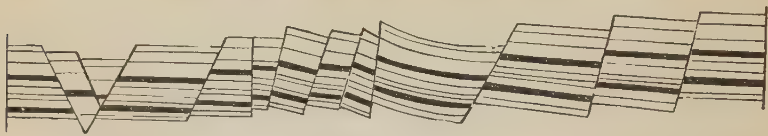


FIG. 440.—Section across Yarrow Colliery, showing the Law of Faults (after De la Beche).

section of Yarrow colliery it will be seen that all the slips follow this law.

Thickness of Seams.—Coal-seams vary in thickness from a fraction of an inch to forty or fifty feet. A workable seam must be at least three feet thick. A pure, simple seam is seldom more than eight or ten feet. Mammoth seams, such as occur in the anthracite region of Pennsylvania, and in Southern France, are produced by the running together of several seams by the thinning out of the interstratified shales and sandstones. They are, therefore, almost always *compound seams*, i. e., separated by thin partings of clay—too thin to form a good roof or floor, and therefore all worked together.

Number and Aggregate Thickness.—In a single coal-field, we have said, the strata, including the coal-seams, are repeated many times. In the South Joggins's section, Nova Scotia, there are eighty-one coal-seams, though most of these are not workable. In North England there are twenty to thirty seams. In South Wales there are more than 100 seams, seventy of which are worked. In South Lancashire there are seventy-five seams over one foot thick; in Belgium 100 seams, and in Westphalia 117 seams. The *aggregate thickness* of all the seams in Lancashire is 150 feet; in Pottsville, Pennsylvania, 113 feet; in Western coal-fields, seventy feet.

The thickest and purest are usually near the middle of the series. Evidently the conditions favorable for the formation and preservation of coal commenced gradually, even back in the Devonian, reached their culmination in the middle Coal-measures, and gradually passed away. This geological day had its morning, its high noon, and its evening.

Coal Areas of the United States.—In no other country are the coal-fields so extensive as in the United States. The principal coal-fields are shown on map of Eastern United States, on page 289.

1. *Appalachian Coal-Field.*—This, the greatest coal-field in the world, commences in Northern Pennsylvania, covers the whole of West-

ern Pennsylvania and Eastern Ohio, a large portion of West Virginia and Eastern Kentucky, then passes southward through East Tennessee, touches the northwest corner of Georgia, and ends in Middle Alabama. In general terms, it occupied the western slope of the Appalachian from the confines of New York to Middle Alabama. Its area is at least 60,000 square miles.

2. *Central Coal-Field.*—This covers the larger portion of Illinois, the southwest portion of Indiana, and the western portion of Kentucky. Its area is about 47,000 square miles.

3. *Western Coal-Field.*—This covers the southern portion of Iowa, the northern and western portion of Missouri, the eastern portion of Kansas, and then passes southward through Arkansas into Texas. Its area is estimated at 78,000 square miles. These two coal-fields are seen to be connected by sub-Carboniferous. They are probably one immense field separated by erosion.

4. *Michigan Coal-Field.*—In the very centre of the State of Michigan there is another coal-field occupying an area of 6,700 square miles.

5. *Rhode Island Coal-Field.*—A small patch of 500 square miles' area is found in Rhode Island, extending a little into Massachusetts.

6. *Nova Scotia and New Brunswick.*—This is a large area on both sides of the bay of Fundy. It is estimated at 18,000 square miles.

The following table gives approximately the areas of American coal-fields of the Carboniferous age:

Appalachian	60,000
Central	47,000
Western	78,000
Michigan	6,700
Rhode Island	500
	192,200
Nova Scotia	18,000
	210,200

Of the 190,000 square miles coal-area of the United States, 120,000 square miles is estimated as workable.

Extra-Carboniferous Coal.—All the fields mentioned above belong to the Carboniferous age. But, besides these, the United States is very rich in coal of other periods. Probably 20,000 to 25,000 square miles might be added from strata of later times, making in all 150,000 square miles of workable coal. But of these latter fields we will speak in their proper places.

Coal-Areas of Different Countries compared.—The following table, taken principally from Dana, exhibits the comparative coal-areas of the principal coal-producing countries of the world:

United States	120,000 to 150,000	square miles.
British America	18,000	"
Great Britain	12,000	"
Spain	4,000	"
France	2,000	"
Germany	1,800	"
Belgium	518	"
Europe, estimated	100,000	"

Relative Production of Coal.—But if the extent of coal-*area* represents approximately the amount of wealth of this kind present in the strata, the *production* of coal represents how much of this wealth is *active capital;* it represents the development of those *industries dependent on coal.* In this respect Great Britain is far in advance of all other countries, as seen by the following table, compiled from the best sources at hand:

ANNUAL COAL-PRODUCTION IN MILLIONS OF TONS.	1845.	1864.	1872.	1874.	1875.
Great Britain	31.5	90	123	125	132
United States	4.5	22	..	50	..
Germany	....	..	..	46	..
Belgium	4.9	10	..	15	..
France	4.1	10	..	17	..

Inspection of the table shows that in the principal coal-producing countries there is a rapid *increase* of production. It is believed that, if the same rate of increase continues, the annual production of Great Britain will be in thirty years 250,000,000 tons, and the whole workable coal will be exhausted in 110 years.[1] As might be expected, therefore, British statesmen and scientists are casting about with much anxiety for means by which to promote the more economic use of coal. Fortunately, our own country is supplied with almost inexhaustible stores of this source of industrial prosperity.

Origin of Coal, and of its Varieties.

That coal is of vegetable origin is now no longer doubtful. We will only briefly enumerate the evidences on which is based the present scientific unanimity on this subject:

1. The remains of an extinct vegetation are found in abundance in immediate connection with coal-seams; stumps and roots in the underclay, and leaves and stems in the black slate in contact with the seam and even imbedded in the seam itself. 2. These vegetable remains are not only associated with the coal-seam, but have often themselves become coal, though still retaining their original form and structure.

[1] Armstrong, *Nature,* vol. vii., p. 291.

3. Not only these easily-recognizable *imbedded* vegetable fragments, but the *imbedding* substance also, the whole coal-seam, even the most structureless portions, and the hardest varieties, such as anthracite, when carefully prepared in a suitable manner and examined with the microscope, show vegetable structure. Even the ashes of coal, carefully examined, show vegetable cells with characteristic markings. The following figures show the results of such examination. 4. A perfect grada-

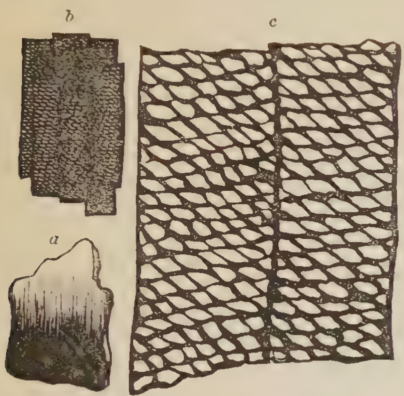


Fig. 441.—Section of Anthracite: *a*, natural size; *b* and *c*, magnified (after Bailey).

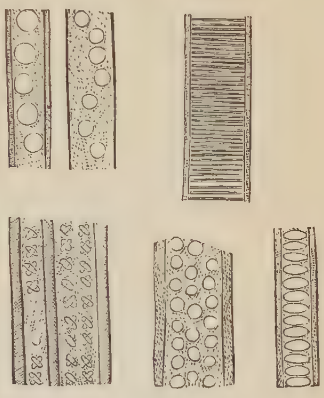


Fig. 442.—Vegetable Structure in Coal (after Dawson).

tion may be traced from wood or peat, on the one hand, through brown coal, lignite, bituminous coal, to the most structureless anthracite and graphite, on the other, showing that these are all different terms of the same series. In chemical composition, too, the same unbroken series may be traced. 5. Lastly, the best and most structureless peat, by hydraulic pressure, may be made into a substance having many of the qualities and uses of coal.

We may, with perhaps less confidence, go farther, and say that all the carbon and hydrocarbon known to us are probably of organic origin. Carbon probably existed at first only as carbonic acid, and has been reduced from that condition only by organic agency.

Varieties of Coal.—The varieties of coal depend upon the *purity*, upon the *degree of bituminization*, and upon the *proportion of fixed and volatile matter.*

Varieties depending upon Purity.—Coal consists partly of organic or combustible and partly of inorganic or incombustible matter. On burning coal, the organic, combustible matter is consumed, and passes away in the form of gas, while the inorganic, incombustible is left as *ash.* Now, the relative proportion of these may vary to any extent. We may have a coal of only one or two per cent. ash. We may have a

coal of five, ten, fifteen, twenty per cent. ash; the coal is now becoming poor. We may have a coal of thirty or forty per cent. ash; this is called *bony coal*, or shaly coal; it is the valueless refuse of the mines. We may have a coal of fifty or sixty per cent. ash; but it now loses the name as well as the ready combustibility of coal, and is called *coaly shale.* Finally, we may have a coal of seventy, eighty, ninety, ninety-five per cent. ash; and thus it passes, by insensible degrees, through black shale into perfect shale. This passage is often observed in the roof of a coal-seam.

Now, all vegetable tissue contains incombustible matter, which, on burning, is left as ash. The amount of ash in vegetable matter is on an average about one to two per cent. But as, in the process of change from wood to coal, much of the organic matter is lost (p. 355, *et seq.*), and the relative amount of ash is thereby increased, we may say that, if a coal contains five per cent. or less of ash, it is absolutely pure—i. e., its ash comes wholly from the plants of which it is composed; but if a coal contains more than ten per cent. ash, it is probably impure—i. e., mixed with mud at the time of its accumulation.

Varieties of Coal depending on the Degree of Bituminization.—The previously-mentioned varieties consist of *pure* and *impure* coals; these consist of *perfect* and *imperfect* coals. We find the vegetable matter, accumulated in different geological periods, in different stages of that peculiar change called bituminization. Brown coal and lignite are examples of such imperfect coal. They are always comparatively modern.

Varieties depending upon the Proportion of Fixed and Volatile Matter. — Coal, even when pure and perfectly bituminized, consists still of many varieties, having different uses, depending upon the proportion of fixed and volatile matters. These are the *true* varieties of coal.

In pure and perfect coal, then, the combustible matter is part fixed and part volatile. These may be easily separated by heating to redness in a retort. By this means the *volatile* matter is all driven off, and may be collected as tar, oil, etc., in condensers, and as permanent gases in gasometers; and the *fixed* matter is left in the retort as coke. Now, the proportion of these may vary greatly in different coals, and affect the uses to which the coal is applied. For example, when the coal consists wholly of fixed carbon, it is called *graphite.* This is not usually considered a variety of coal, because it is not readily combustible; but it is evidently only *the last term of the coal series.* Its soft, greasy feel, and its uses for pencils, as a friction-powder, and as a material for crucibles, are well known.

When the combustible matter of the coal contains ninety to ninety-five per cent. fixed carbon, it is called *anthracite.* This is a hard, brill-

iant variety, with conchoidal fracture and high specific gravity. It burns with almost no flame and produces much heat. It is an admirable coal for all household purposes, and, with *hot* blast, may be used in iron-smelting furnaces.

If the combustible matter contains eighty to eighty-five per cent. fixed carbon, and fifteen to twenty per cent. volatile matter, it becomes semi-anthracite or semi-bituminous coal, of various grades. These are free-burning, rapid-burning coals, producing long flame and high temperature, because they do not cake and clog. They are admirably adapted for many purposes, but especially for the rapid production of steam, and therefore for locomotive-engines, and hence are often called *steam-coals.*

If the volatile combustible matter rises to the proportion of thirty to forty per cent., it becomes full bituminous coals, which always burn with a strong, bright flame, and often *cake* and form clinkers. This is perhaps the commonest form of coal, and may be regarded as *typical* coal.

If the volatile matter approaches or exceeds fifty per cent., then it forms *highly-bituminous* or *fat* or *fusing* coals. This variety is especially adapted to the manufacture of gas and of coke.

Besides these there are several varieties depending on physical character. Thus cannel or parrot coal is a dense, dry, structureless, lustreless, highly-bituminous variety, which breaks with a conchoidal fracture. There may be also some varieties depending upon the kind of plants of which coal was made, but of this we have no certain evidence.

Origin of these Varieties.—There can be little doubt that these, the true varieties, are produced by slight differences in the nature and degree of chemical change in the process of bituminization.

It will be seen by the following table, giving approximate formulæ, that vegetable matter and coal of various grades have the same general composition, except that in the latter case some of the carbon and much of the hydrogen and oxygen have passed away in the process of change:

Vegetable matter, cellulose	$C_{36}H_{60}O_{30}$
Bituminous coal	$C_{26}H_{10}O_2$
Anthracite "	$C_{40}H_8O$
Graphite "	C pure

The excess of the hydrogen and oxygen lost is still better shown in the following table, in which the constituents are given in proportionate weights instead of equivalents, and the carbon reduced to a constant quantity:

KINDS OF VEGETABLE MATTER AND COALS.	Carbon.	Hydrogen.	Oxygen.
Cellulose	100.00	16.66	133.33
Wood	100.00	12.18	83.07
Peat	100.00	9.83	55.67
Lignite	100.00	8.37	42.42
Bituminous coal	100.00	6.12	21.23
Anthracite "	100.00	2.84	1.74
Graphite "	100.00	0.00	0.00

Now, there are two modes of decomposition to which vegetable matter may be subjected, viz.: 1. In contact with air; and, 2. Out of contact with air. The first is partly decomposition, and partly oxidation by the air (*eremacausis*); the second is wholly decomposition.

In Contact with Air.—Under these conditions, the carbon of the vegetable matter unites with the *oxygen of the vegetable matter*, forming carbonic acid (CO_2); and the hydrogen of the vegetable matter unites with the oxygen of the *air*, forming water (H_2O). Further, it is evident that for every equivalent of carbon thus lost there are two equivalents of oxygen and four equivalents of hydrogen lost, so as always to maintain the same relative proportion of H and O, viz., the proportion forming water (H_2O). The final result of this process is *pure carbon*. It is very improbable, however, that anthracite or graphite is formed in this way; for vegetable matter, by aërial decay, falls to powder. It is very probable, however—nay, almost certain—that a peculiar substance, pulverulent and retaining vegetable structure in a remarkable degree, called *mineral charcoal*, found very commonly in some stratified coals, has been formed by partial aërial decay, somewhat as represented in the table. Mineral charcoal has a high percentage of carbon, with very little hydrogen and oxygen.

Cellulose	$C_{36}H_{60}O_{30}$
Decayed	$C_{35}H_{56}O_{28}$
More decayed	$C_{34}H_{52}O_{26}$
Final result	C_{21}

Out of Contact with Air.—When vegetable matter is buried in mud or submerged in water, its *elements react on each other*. Some of the carbon unites with some of the oxygen, forming carbonic acid (CO_2); some of the carbon unites with some of the hydrogen, forming carbureted hydrogen, or marsh-gas (CH_4); and some of the hydrogen unites with some of the oxygen, forming water (H_2O). These products are probably formed in all cases of vegetable decomposition under these conditions. If, for example, we stir up the mud at the bottom of stagnant pools where weeds are growing, the bubbles which rise always consist of a mixture of CO_2 and CH_4. In every coal-mine these same gases are constantly given off; the one being the deadly *choke-damp* and the other the terrible *fire-damp* of the miners. Now, by varying the relative amounts of these products, it is easy to see how all the

principal varieties of bituminous coal may be formed. I have given below the approximate composition of typical varieties of bituminous coal, and of graphite, and constructed formulæ expressing the chemical change by which they are formed:

Vegetable matter—cellulose	$C_{36}H_{60}O_{30}$ [1]	
Subtract $\left\{\begin{matrix} 9CO_2 \\ 3CH_4 \\ 11H_2O \end{matrix}\right\}$	$C_{12}H_{34}O_{29}$	
And there remain	$C_{24}H_{26}O$	= cannel.
Again, vegetable matter	$C_{36}H_{60}O_{30}$	
Subtract $\left\{\begin{matrix} 7CO_2 \\ 3CH_4 \\ 14H_2O \end{matrix}\right\}$	$C_{10}H_{40}O_{28}$	
And there remain	$C_{26}H_{20}O_2$	= bituminous coal from Staffordshire.
Again, vegetable matter	$C_{36}H_{60}O_{30}$	
Subtract $\left\{\begin{matrix} 10CO_2 \\ 10CH_4 \\ 10H_2O \end{matrix}\right\}$	$C_{20}H_{60}O_{30}$	
And there remains	C_{16}	= graphite.

The composition of vegetable matter varies considerably. The composition of the varieties of coal is differently given by different authorities. Different reactions from those above given might be contrived which would give as good results. These reactions, therefore, are not given as certainly the actual reactions which take place. They are only intended to show the general character of the changes which take place in the formation of coal.

Metamorphic Coal.—It is probable that bituminous coal is the *normal* coal formed by the above process, and that the extreme forms, anthracite and graphite, are the result of an after-change produced by heat. But some geologists go further: they believe that anthracite has been changed by intense heat sufficient to vaporize the volatile matters, which then condense in fissures above, as bitumen, petroleum, etc.; that, as in art, when bituminous coal is subjected to heat out of contact with air, the fixed carbon is left as coke, the tarry and liquid matters are condensed in purifiers, and the permanent gases collected in gasometers: so in Nature, when beds of bituminous coal are subjected to intense heat in the interior of the earth, the fixed carbon is left as

[1] The composition of *wood—timber*—is usually given as about $C_{12}H_{18}O_8$. I have taken the formula of cellulose instead, viz., $C_6H_{10}O_5$; or, taking six equivalents for convenience of calculation, $C_{36}H_{60}O_{30}$. I believe this to be much nearer the composition of vegetable matter of the *Coal period* than is the formula of hard wood like oak or beech. All the results may be worked out, however, with equal ease in either formula for vegetable matter.

anthracite, the tarry and liquid matters collected in fissures, as bitumen and petroleum, while the gases escape in burning springs. The process is of course slow and under heavy pressure, and therefore the residuum is not spongy like coke. According to this view, anthracite and bitumen are necessary correlatives.

There can be no doubt that the graphitic and anthracitic varieties of coal are always associated with folding and metamorphism of the strata: 1. In the universally-folded and metamorphic Laurentian rocks only graphite is found. 2. In Pennsylvania, in the strongly-folded and highly-metamorphic eastern portion of the field, the coal is anthracite; while, as we go westward, and the rocks are less and less metamorphic, the coal is more and more bituminous, until, when the rocks are horizontal and unchanged, the coal is always highly bituminous. The same has been observed in Wales: anthracite is always found in metamorphic regions, and the coal is more and more bituminous as the rocks are less and less metamorphic. 3. Again, the anthracitic condition of coal may be sometimes traced to the local effect of trap or volcanic overflows. In a word, anthracite is *metamorphic* coal; and, according to this view, the same heat which changed the rocks has distilled away the volatile matters, which may condense above, as bitumen or petroleum.

We have given above the common view. It is partly true and partly erroneous. The true view seems to be as follows:

Anthracite may, indeed, be regarded as metamorphic coal, but it is not probable that bitumen is its necessary correlative; it is not probable that the heat of metamorphism is sufficient to produce destructive distillation. We have already shown (p. 223) that a moderate heat of 300° to 400° Fahr. in the presence of water is sufficient to produce metamorphism. Such a degree of heat would, doubtless, hasten the process explained on page 223. The folding and erosion of the rocks, and the consequent exposure of the edges of the seams, would still further hasten the process, and bring about anthracitism by facilitating the escape of the products of decomposition. In all coal-mines CO_2, CH_4, and H_2O, are eliminated *now;* only continue this process long enough, and anthracite and, finally, graphite is the result. We must conclude, then, that high heat is not necessary to produce anthracitism; for, if it is unnecessary for metamorphism of *rocks*, much less is it necessary for metamorphism of *coal*.

Plants of the Coal—their Structure and Affinities.

The flora of the coal-measures is the most abundant and perfect of all extinct floras. Of about 2,500 to 3,000 known fossil species of plants nearly 700, or about one-fourth, are from the coal-measures. This flora is peculiarly interesting to the geologist, not only on account of its relative abundance, but also and chiefly because being the first diversified

and somewhat highly-organized flora, it is natural to suppose that *the great classes and orders of the vegetable kingdom commenced to diverge here.* We will, therefore, discuss the affinities of these plants somewhat fully.

Where found.—The plants of the Coal are found principally: 1. In the form of *stools and roots* in their original position in the *underclay;* 2. Of *leaves*, and *branches*, and *flattened trunks*, on the upper surface of the coal-seam, and in the overlying *shale;* 3. And, finally, in the form of *logs*, apparently drift-timber, in the *sandstones* above the coal-seam. The black shale overlying the seam is often full of leaves and fronds of ferns, and of the flattened trunks of other families, in the most beautiful state of preservation, so that even the finest venation of the leaves is perfectly distinct. In some cases where the shale is light-colored, so as to contrast strongly with the jet-black leaves, the effect on first opening a seam is very striking, and has been compared to the frescoes on the ceilings of Italian palaces.

Principal Orders.—Leaving out some plants of doubtful affinity, the plants of the Coal may be referred to five orders or families, viz., *Conifers*, *Ferns*, *Lepidodendrids*, *Sigillarids*, and *Calamites.* It is usual to refer these last three to the two orders Lycopods and Equisetæ; but they are so peculiar, and their affinities still so doubtful, that we have preferred to treat them as distinct orders.

All these, as already seen, commenced in the Devonian, as did also the preservations of their tissues as coal; but both the vegetation and the conditions necessary for their preservation culminated in the Coal period, and therefore we have put off their discussion until now. Contrary to our usual custom, we will commence with the highest, viz.:

1. Conifers.—These are found mostly in the form of *stumps*, and *logs*, and *fruit*, and *leaves.* The logs are found mostly in the sandstones, and therefore have been supposed, and apparently with good reason, to be the remains of drift-logs of the highland trees of the times, carried down by rapid currents. They are known to be conifers by the exogenous structure of the trunk, together with the discigerous tissue of the wood (Fig. 373 p. 328), and in some cases by the foliage (Fig. 446) and by the fruit. Several genera have been described, but they all differ greatly from the ordinary conifers of temperate climates. Their nearest living congeners seem to be among the tropical family *Araucariæ* (Norfolk Island pine), or among the broad-leaved conifers like the *Salisburia* of China (Fig. 444), and the curious *Welwitschia* of South Africa (Fig. 443). This last anomalous conifer, with a trunk three or four feet in diameter, and only one foot high, bears but two strap-shaped leaves (the first leaves of the plumule[1]) of great size (two or three feet wide and six feet long), which last during its whole life of 100 years (Maout and Decaisne).

[1] *Nature*, vol. xxii., p. 590. 1880.

The Cordaites is now usually referred to the Conifers,[1] though so anomalous in its foliage. It formed a straight trunk, sometimes sixty to seventy feet long, clothed atop with long, strap-shaped leaves like the Dracæna. Fig. 447 is a restoration by Dawson.

Nut-like fruits, called Trigonocarpus, Cardiocarpus, Rhabdocarpus, etc., found in great numbers in the Coal-measures, are referred to Coni-

FIG. 443.

FIG. 444 c.

FIG. 444 a.

FIG. 445.

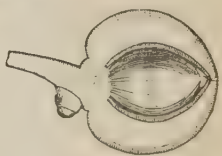


FIG. 444 b.

FIGS. 443–445.—BROAD-LEAVED CONIFERS. LIVING CONGENERS OF SOME COAL-PLANTS: 443. Welwitschia (the whole plant). 444. Salisburia (Ginko): *a*, a branch; *b*, section of fruit; *c*, a leaf, natural size. 445. Phyllocladus, a branch.

fers. Trigonocarpus is very similar in structure to the nuts of the Salisburia, the Torreya or California nutmeg, and the yew, or possibly

[1] Some place them among Cycads.

to those of Cycads. Cardiocarpus is strikingly similar to the winged nut of the Welwitschia. It is believed to be the fruit of Cordaites.

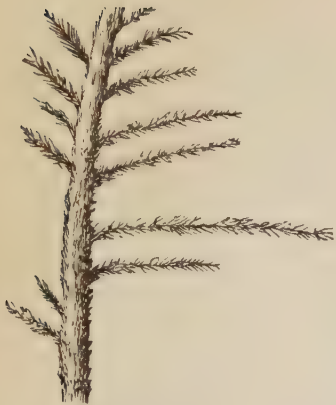


FIG. 446.—Araucarites gracilis, reduced (after Dawson).

FIG. 447.—Cordaites (restored by Dawson).

The anomalous forms called Antholithes are supposed by Newberry to be the fruit of allies of Cordaites.

Affinities of Carboniferous Conifers.—The affinities of the early Conifers are very obscure, but there is little doubt that they were all remarkable *generalized types.* They seem to be allied, on the one hand, through the Araucariæ and the Lepidodendrons, *with the Club-mosses;* and on the other, through the broad-leaved yews, such as Salisburia, Phyllocladus, etc., *with the Ferns.* The leaf of a Salisburia (Fig. 444) is dichotomously veined like a fern. A leafy branch of a Phyllocladus (Fig. 445) is strikingly like that of a Coal-fern, Cyclopteris (Noeggerathia). Some of the Conifers of this period differ from all living Conifers, in having a large pith (Fig. 461), and a somewhat loose tissue, which may be regarded as an embryonic character.

In conclusion, the Conifers of the Coal are undoubted Conifers, but have a decided alliance with the vascular Cryptogams, viz., with Lycopods, especially the gigantic Lycopods of the Coal, and with Ferns.

2. **Ferns.**—Ferns are the most abundant plants of the Coal period, both as to individuals and as to variety of *species.* About one-third to one-half of all the known species of coal-plants, both in this country and in Europe, belong to this order. They represent both ordinary forms, i. e., those with creeping stems, and *Tree-ferns*, like those now growing only in warm latitudes (Fig. 463). They are known to be

ferns by their large complex fronds (Fig. 464), sometimes six to eight feet long; by the dichotomous venation of their leaves (Fig. 467 *a*);

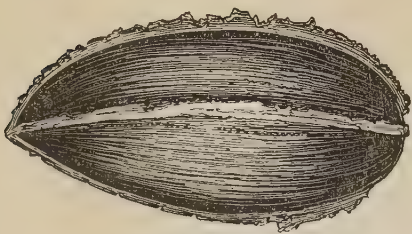


Fig. 448.


Fig. 449.


Fig. 450.


Fig. 451.


Fig. 452.


Fig. 453.


Fig. 454.


Fig. 455.


Fig. 456.


Fig. 457.


Fig. 458.


Fig. 459.

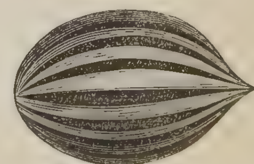


Fig. 460.

Figs. 448–460.—Fruits of Coal-Plants, probably Conifers: 448–450 Trigonocarpon (after Newberry). 451–458. Cardiocarpon (after Newberry and Dawson). 459, 460. Rhabdocarpon (after Newberry).

and by the position of their organs of fructification (*spore-cases*) on the

under surfaces of the leaves (Figs. 468 and 469). In some localities these spore-cases are so abundant that the coal seems to be almost wholly made up of them. The trunks of Tree-ferns are known by the

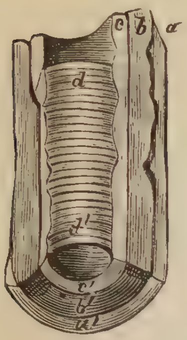


FIG. 461.—Trunk of a Conifer: *a*, bark; *b*, wood; *c*, medullary sheath; *d*, pith.

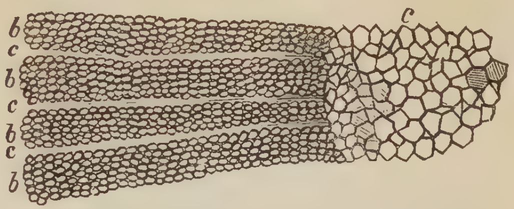


FIG. 462.—Section of same: *b*, woody wedges; *c*, pith and pith-rays.

large, ragged, ovoid marks left by the falling of the fronds (leaf-scars—Figs. 478 and 479), and by the peculiar arrangement of the *vascular* tissue in the cellular in the cross-section. Some coal Tree-ferns had their large fronds in two vertical ranks (Megaphyton—Fig. 464).

FIG. 463.—Living Tree-Fern.

FIG. 464.—Megaphyton, a Coal-Fern restored (after Dawson).

The Ferns of the Coal are, therefore, unmistakably Ferns, yet botanists recognize some features which connect them with other classes. Caruthers thinks that he finds in the internal structure of the stems of

FIG. 465.

FIG. 466.

FIG. 467.

FIG. 467 *a*.

FIG. 468.

FIGS. 465-468.—COAL-FERNS: 465. Callipteris Sullivanti (after Lesquereux). 466. Pecopteris Strongii (after Lesquereux). 467. Alethopteris Massilonis (after Lesquereux); *a*, same enlarged to show dichotomous venation. 468. Neuropteris flexuosa (after Brongniart).

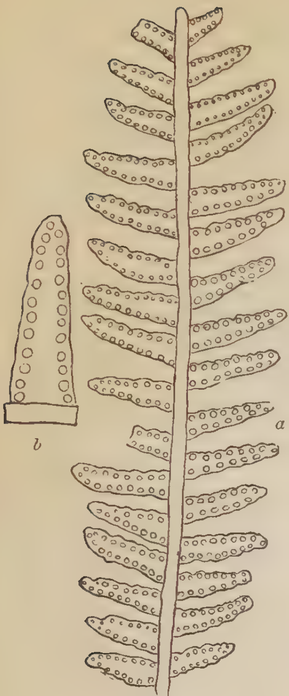


Fig. 469.

Fig. 470.

Fig. 471.

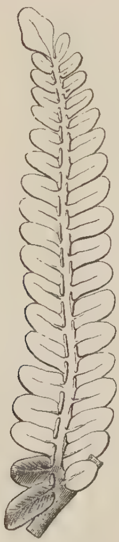


Fig. 472.

Fig. 473.

Fig. 474.

Figs. 469–474.—Coal-Ferns: 469. Pecopteris Strongii, showing fructification; *b*, a leaflet enlarged (after Lesquereux). 470. Odontopteris Wortheni (after Lesquereux). 471. Hymenophyllites alatus (after Lesquereux). 472. Neuropteris flexuosa (after Lesquereux). 473. Neuropteris hirsuta (after Lesquereux). 474. Alethopteris lonchitica (after Lesquereux).

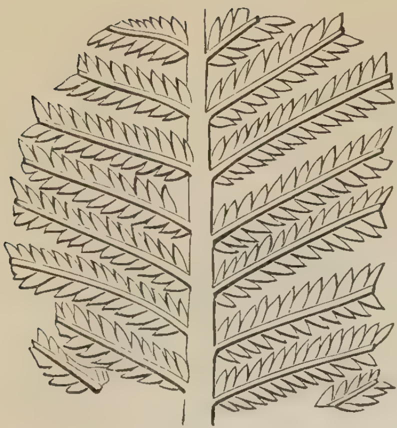


FIG. 475.

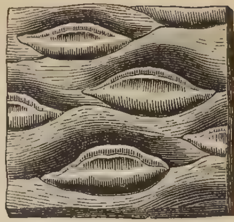


FIG. 477.

FIG. 478.

FIG. 476.

FIG. 479.

FIGS. 475–479.—COAL-FERNS: 475. Odontopteris gracillima (after Newberry). 476 Hymenophyllites splendens (after Lesquereux). 477. Leaf-Scars of Palæopteris, × $\frac{1}{2}$ (after Dawson). 478. Leaf-Scar of Megaphyton, × $\frac{1}{8}$ (after Dawson). 479. Caulopteris primeva, showing Leaf-Scars.

Tree-ferns of the Coal two types which are the foreshadowings of the Monocotyls on the one hand, and the Dicotyls on the other; and that therefore they are probably the progenitors, not only of the Tree-ferns of the present day, but also of the Palms and the foliferous Exogens.[1]

The next three orders we will discuss more fully for two reasons: First, the *Conifers* were probably mostly highland plants, and only found their way into the coal-swamps by accident, being in fact brought down by freshets. The Ferns formed the thick underbrush of the coal-swamps. Neither of these contributed a very large share to the material of the coal-seams. The great trees of the coal-swamps,

[1] *Nature*, vol. vi., p. 480, and Scott, *American Journal*, vol. ix., p. 65.

and which formed the larger part of the material preserved as coal, were *Lepidodendrids*, *Sigillarids*, and *Calamites*.

Again, the Conifers and Ferns were unmistakably Conifers and Ferns, though certainly with characters connecting with other orders and classes; but the three orders now about to be discussed combine so completely the characters of widely-separated classes that there is still some doubt as to their real place. For that very reason, however, they are peculiarly interesting to the evolutionist.

3. **Lepidodendrids.**—These are so called from the typical genus *Lepidodendron*. We will describe only this genus.

Lepidodendrons are found most commonly in flattened masses representing portions of the trunk or branches, very regularly marked in rhomboidal pattern, and much resembling the impression of the scaly surface of a Ganoid fish. The name Lepidodendron (scale-tree) is derived from this fact (Figs. 481–483). These marks are the scars of the regularly-arranged and crowded leaves. All portions of the plant, however, viz., the roots, the trunk, the branches, the leaves, and the fruit, have been found in abundance. From these the general appearance of the tree has been approximately reconstructed. Imagine, then, a tree two to four feet in diameter at base, forty to sixty feet high, with wide-spreading *roots*, well adapted for support on a swampy soil; the *surface* of the trunk and branches regularly marked in rhomboidal pattern, representing the phyllotaxis; the *trunk* dividing and subdividing, but not profusely, into branches, which are thickly clothed with scale-like, or spine-like, or needle-like leaves (Figs. 484 and 486), and terminated by a club-shaped extremity like the terminal cones of some conifers, or still more like the club-shaped extremities of club-mosses (Figs. 485, 487, 488): and we will have a tolerably correct idea of the Lepidodendron.

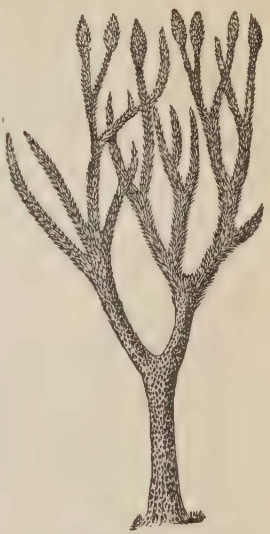


FIG. 480.—Restoration of a Lepidodendron, by Dawson.

The general appearance of the tree is that of an Araucarian conifer, or of a gigantic club-moss. The fruit, however, turns the scale of affinity in favor of the club-moss; for the examination of these, which are found in great abundance, and known under the name of *Lepidostrobus* (scale-cone), has shown that they bear in the axils of their scales *spores* like club-mosses, and not *seeds* like conifers. Also, like club-mosses, there are in these plants two kinds of spores[1]—microspores and

[1] Williamson, *Nature*, vol. viii., p. 498.

macrospores—corresponding to stamens and pistils (Fig. 489). This would again ally them very closely with conifers. The external ap-

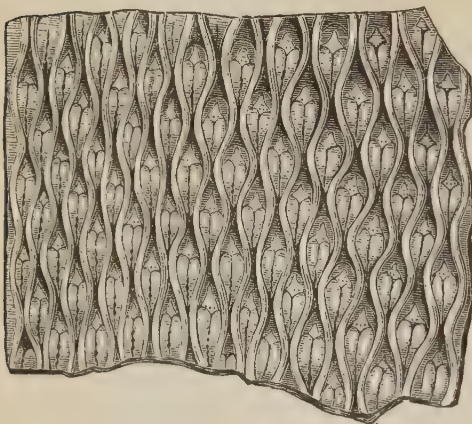


FIG. 481.

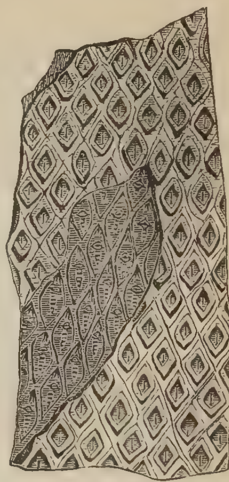


FIG. 482.

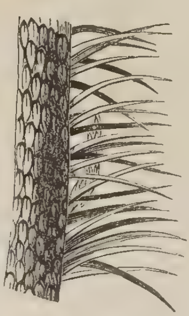


FIG. 483

FIG. 484.

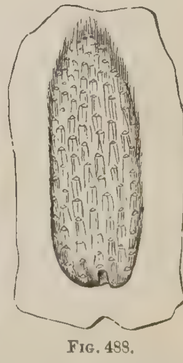


FIG. 486. FIG. 485. FIG. 488. FIG. 487.

FIGS. 481–488.—LEPIDODENDRIDS: 481. Lepidodendron modulatum (after Lesquereux). 482. Lepidodendron diplotegioides (after Lesquereux). 483. Lepidodendron politum (after Lesquereux). 484. Lepidodendron corrugatum, branch and leaves (after Dawson). 485. Lepidodendron corrugatum, branch and fruit (after Dawson). 486. Lepidodendron rigens (after Lesquereux). 487. Lepidophloios Acadianus, fruit (after Dawson). 488. Lepidostrobus (after Lesquereux).

pearance and inflorescence, therefore, indicate that they are Lycopods, with very strong coniferous affinities.

This conclusion is entirely borne out by the *internal structure.* Fig.

FIG. 489.—Lepidodendron compared with Club Moss: *a*, club-moss; *b*, a scale enlarged; *c*, microspores; *d*, macrospores; *x*, lepidostrobus; *y* and *z*, the scales containing spores; *m*, microspores; *n*, macrospores (after Balfour).

490 represents an ideal cross and longitudinal section of the stem of a Lepidodendron. It is seen that the stem consists of a dense outer bark or rind, inclosing a great mass of loose cellular tissue or inner bark, through the centre of which runs a comparatively small fibro-vascular cylinder, with very distinct pith. Bundles go from the cylinder outward to form the venation of the leaves. Now, the structure of a club-moss is almost the same, except that the fibro-vascular cylinder is solid, and there is, there-

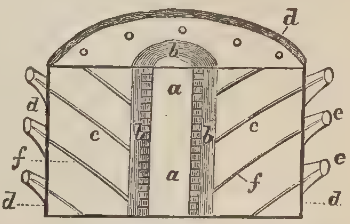


FIG. 490.—Ideal Section of a Lepidodendron: *a*, pith; *b*, vascular cylinder; *c*, inner bark; *d*, rind; *e*, bases of leaves; *f*, vascular threads going to the leaves.

fore, no *pith.* The presence in Lepidodendron of a distinct pith is an important character, placing it far above modern Lycopods, and allying it most decidedly with Exogens.

4. **Sigillarids.**—The typical genus of this family is *Sigillaria.* These plants are found, like Lepidodendrids, mostly as flattened masses,

FIG. 491.

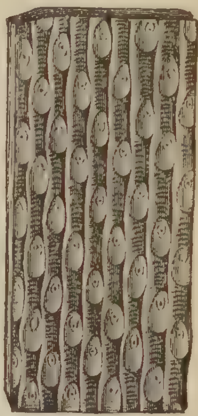


FIG. 492.

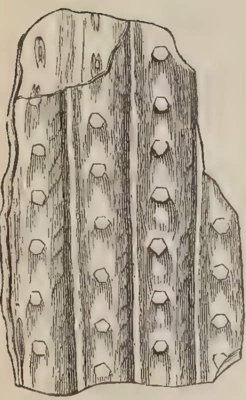


FIG. 493.

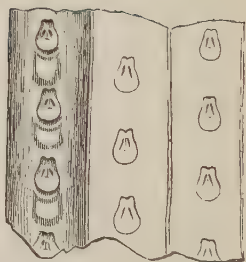


FIG. 494.

FIG. 495.

FIGS. 491–495.—SIGILLARIDS: 491. Sigillaria reticulata (after Lesquereux). 492. Sigillaria Græseri. 493. Sigillaria lævigata (European). 494. Sigillaria obovata (after Lesquereux). 495. Leaf of Sigillaria elegans (after Dawson).

which are portions of trunks, but also as *roots* and *leaves.* The trunk-impressions are distinguished from those of Lepidodendrids by longi-

tudinal ribbings or flutings, ornamented with seal-like impressions (*sigilla*, a seal), in vertical rows (Figs. 491–494). Little is known of their leaves, though they seem to have been similar to those of Lepidodendron (Fig. 495).

The best general conception which we can form of the Sigillaria would represent it as a tall, gently-tapering trunk, longitudinally fluted like a Corinthian column, and ornamented with seal-like impressions in vertical ranks, representing the phyllotaxis; unbranched or else dividing only into a few large branches, clothed thickly with long, stiffish, tapering leaves. From the base of the trunk extended large, radiating roots, branching dichotomously and sparsely, with many long, thread-like rootlets penetrating the soil below. The stumps of Sigillaria and Lepidodendrons, with these large, horizontally-spreading roots and thread-like appendages, are very common in the underclay, and were long supposed to be a peculiar plant, and called Stigmaria, on account of the round spots (*stigma*) on their surface. They are now known to belong to Sigillarids and Lepidodendrids, and are either roots or spreading rhizomes (underground branches).

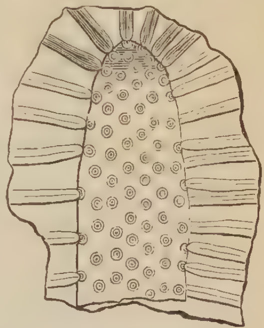


FIG. 496.—Stigmaria ficoides (after Lesquereux).

In the following figure (497), taken from Dawson, we have attempted to realize the general appearance of a Sigillaria. Their trunks were sometimes of prodigious length and diameter. They were probably the largest trees of the time. In a coal-seam in Dauphin County, Pennsylvania, flattened stems were found four feet and even five feet in width. Some of these were exposed for fifty feet, with but little apparent diminution. One was exposed sixty-five feet, and was estimated to have extended at least thirty feet more. Another was exposed seventy feet, and was estimated to have been eighty to one hundred feet when growing.[1]

The Sigillarids are regarded as closely allied to the Lepidodendrids. Indeed, the two families shade into each other in such wise that there are many genera the position of which, whether in the one family or in the other, is doubtful. The typical Sigillaria, however, differs in general port from the typical Lepidodendron, chiefly in possessing a more Palm-like, or Cycas-like, or Dracena-like stem. They are evidently, like the Lepidodendrids, closely allied to *Lycopods*, but their alliance with higher classes is even stronger than that of Lepidodendrids.

The internal structure of the stem entirely confirms this conclusion. A cross-section (Fig. 498) of a Sigillaria-stem shows a hard external rind, *d*, inclosing a great mass of loose, cellular tissue (inner bark),

[1] Taylor, "Statistics of Coal," pp. 149, 150; Williamson, *Nature*, vol. viii., p. 447.

c c, through the centre of which runs a comparatively small woody cylinder, *b b*, and in the centre of this again a large pith, *a a*. From the woody cylinder go bundles of fibro-vascular tissue, *f f*, through the cellular tissue of the inner bark, to the leaves, *e e*. Thus far the description is like the Lepidodendron, except that the woody cylinder is larger and thicker; but closer examination shows, in addition, the woody cylinder divided into *woody wedges* by *medullary rays*, *g g*, in true exogenous style, though the concentric rings characteristic of Exogens are wanting. Still closer examination with the microscope shows a *true gymnospermous tissue* (p. 328, Figs. 373–375), both on cross and longitudinal section. Now, there is no plant living which combines gym-

FIG. 497.—Restoration of Sigillaria, by Dawson.

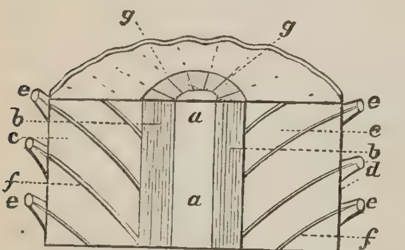


FIG 498.—Ideal Section of a Sigillaria-Stem: *a*, pith; *b*, woody cylinder; *c*, inner bark; *d*, rind; *e*, bases of leaves; *f*, vascular thread running to the leaves; *g*, medullary rays.

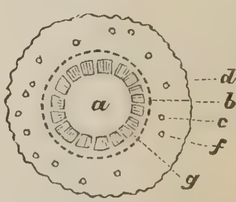


FIG. 499.—Cross-Section of Stem of Cycas.

nospermous tissue with a general stem-structure at all similar to this, except *Cycads* (Cycas, Zamia, etc.). For sake of comparison, we have given (Fig. 499) a cross-section of a Cycas; the letters represent the same as in the previous figure. There can be no reasonable doubt, therefore, of the close alliance of the *Sigillarids* with the *Cycads.* But their close connection with Lepidodendrids shows an equally close, or closer, alliance with Lycopods. So thoroughly are they a connecting type that some paleontological botanists (Dawson) regard them as Cycads with strong Lycopod affinities, while most regard them as Lycopods with strong Cycad affinities.

5. **Calamites.**—These are plants having long, slender, tapering, reed-like stems, jointed and hollow, or else with large pith. The exterior

FIG. 500.

FIG. 501.

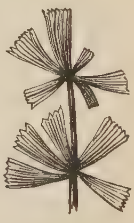


FIG. 502.

FIG. 503.

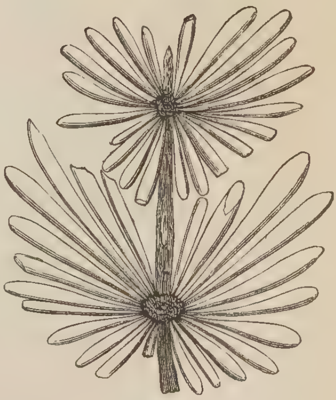


FIG. 504.

FIGS. 500–504.—CALAMITES AND THEIR ALLIES: 500. Lower End of Stem of Calamites from Nova Scotia. 501. Lower End of Stem of Calamites cannæformis. 502. Sphenophyllum erosum (after Dawson). 503. Asterophyllites foliosus, England (after Nicholson). 504. Annularia inflata (after Lesquereux).

surface of the stem is finely striated or fluted, but the striæ are not continuous nor marked with leaf-scars like the flutings of the Sigillaria, but are interrupted at the joints in the manner shown in Figs. 500 and 501. At the joints are attached in whorls the leaves, which are either scale-like, or strap-like, or thread-like. Sometimes at the joints of the main stem come out in whorls thread-like, jointed branches, bearing scale-like or thread-like leaves. At the lower end of the stem, the joints grow rapidly smaller and shorter, so that this end was conical. From these short, rapidly-tapering joints came out the *thread-like roots.*

What I have said thus far applies word for word to Equisetæ; but the Equisetæ of the present day are small, rush-like plants, never much thicker than the finger, and seldom more than three or four feet high, although in South America (Caracas) they grow thirty feet high, but are very slender; while Calamites were certainly two feet or more in diameter, and thirty feet high. Fig. 505 is an attempt to reconstruct the general appearance of a Calamite by Dawson.

Fig. 505.—Restoration of a Calamite (after Dawson).

The internal structure of Calamites still further removes them from Equisetæ; for they seem to have had (some of them, at least) a thick, woody cylinder of *exogenous structure* and *gymnospermous tissue.* And if, as Williamson supposes,[1] many of the striated jointed stems called Calamites are only casts of the pith, the stems must have been even much larger than stated above.

Thus, as Lepidodendrids connected Lycopods with Conifers, and Sigillarids connected Lycopods with Cycads, so these connected Equisetæ with Conifers.

General Conclusion.—The conclusion which we draw from this examination of Coal plants is: 1. That they belong to the highest Cryptogams, viz., Vascular Cryptogams, and the lowest Phænogams, viz., Gymnosperms; 2. That they were intermediate between these now widely-separated classes, and connected them closely together. These facts are strictly in accordance with the law already announced (p. 344), viz., that the earliest representatives of any class or order are not *typical* representatives of that class or order, but connecting or comprehensive types—that is, types which, along with their distinctive classic or ordinal character, united others which connected them with other classes or orders. Thus the now widely-separated classes and orders of organisms, when traced backward, in time approach each other more and more, and probably unite in one common stem, although we are seldom able to find the

[1] *Nature*, vol. viii., p. 447.

point of actual union. Thus, in this case, the now widely-separated Cryptogams and Phænogams, when traced backward, approach until in the Coal they are nearly, if not completely, united. The organic kingdom may be compared to a tree whose trunk is probably to be found, if found at all, in the lowest strata; its main branches begin to separate in the Palæozoic, the secondary branches in the Mesozoic, and so the branching continues until the extreme ramification, but also the flower and fruit, are found in the fauna and flora of the present day. The duty of the evolutionist is to trace each bough to its fellow-bough, and each branch to its fellow-branch, and thus gradually to reconstruct this tree of life, and determine the *law* and the *cause* of its growth.

Theory of the Accumulation of Coal.

There is no question connected with the Carboniferous period concerning which there has been more discussion than the mode in which coal has been accumulated. There are some things, however, about which there is little difference of opinion. These we will state first, and thus narrow the field of discussion.

Presence of Water.—That coal has been accumulated in the presence of water, or at least of abundant moisture, is evident: *a.* From the *preservation* of the organic matter. By aërial decay vegetable matter is either entirely consumed, or else crumbles into dust. Only in the presence of water is it preserved and accumulated in larger quantities. *b.* The interstratified sand and clays and limestones have, of course, been deposited like all strata in water. *c.* The coal itself is not unfrequently distinctly and finely *stratified.* *d.* The plants found in connection with the coal-seams are mostly such as grow in moist ground.

Thus far, then, theorists agree, but from this point opinions diverge, and until recently have very widely diverged. Some have thought that coal has accumulated by the growth of plants "*in situ*," as in peat-bogs and peat-swamps of the present day. Others have supposed that it has accumulated by driftage of vegetable matter by rivers, like the rafts now found at the mouths of great rivers of the present day. According to the one view, a coal-seam is an ancient *peat-swamp;* according to the other, it is an immense *buried raft.* The one is called the "*Peat-bog theory,*" the other, the "*Estuary or raft theory.*"

Recently, however, scientific opinions have converged toward a common belief. We will not, therefore, discuss these two rival theories, but simply bring out what is most certain in the present views on this subject.

1. *Coal has been accumulated by growth of vegetation in situ, as in peat-swamps of the present day.* This fact is now demonstrable. The reasons for believing it are the following: *a.* *The purity of coal.*

The coals of the American coal-fields are, with few exceptions, absolutely pure, i. e., the amount of ash is not greater than would result from the ash of the plants of which it is composed. The same is true of coals of most extensive coal-fields everywhere. Now, it has already been shown (p. 135) that in extensive peat-swamps, like the Great Dismal Swamp, absolutely pure vegetable accumulations unmixed with sediment occur; but in buried rafts or drifted vegetable matter of any kind there must be a large admixture of mud. *b. The preservation of the most complex and delicate parts of the plant in their natural relations to each other.* Large fronds are spread out and pressed as in a botanist's herbarium. Delicate leaves are preserved with all their finest venation perfectly visible. This is exactly what we would expect if they lay where they fell, but is incompatible with driftage by rapid currents to long distances. *c. The position of these perfect specimens only on the upper part of the seam*, as would be the case with the *last* fallen leaves, instead of mixed throughout the seam, as would be the case with drifted matter. *d. The presence of stumps with their spreading roots penetrating the underclay exactly as they grew.* This is not an occasional phenomenon, but is found in the underclay of nearly every coal-seam. In South Wales there are 100 seams of coal, every one of which is underlaid by clay crowded with roots and sometimes with stumps. In Nova Scotia there are seventy-six seams, twenty of which have erect stumps standing in their original position with spreading roots still penetrating the underclay. The other seams have each its underclay filled with stigmaria-roots. Besides these seams there are many dark bands (dirt-beds) indicating old forest-grounds.

The following section (Fig. 506) shows some of these seams and dirt-beds or forest-grounds, with penetrating roots and erect trunks.

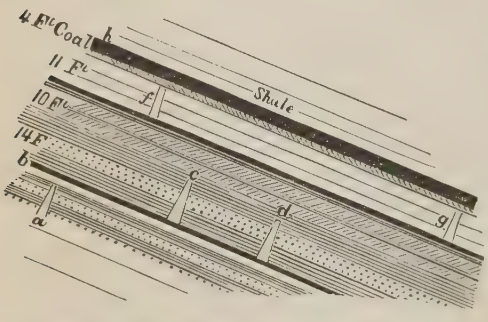


FIG. 506.– Erect Fossil Trees, Coal-Measures, Nova Scotia.

Fig. 507 shows an area of about one-quarter acre of surface of the underclay of an English coal-seam in which there are seventy-three stumps *in situ*. This last evidence (*d*) is demonstrative. Beneath every coal-seam there is a fossil soil — an ancient forest-ground.

Recapitulation. — We may sum up the evidence, and at the same time make it clearer, by describing a section of a peat-bog, and comparing with a coal-seam. In such a section we have always an underclay, on which accumulated the moisture, and on

which grew the original trees of the locality. This underclay is often full of roots and stumps of the original growth. Above this is a fine, structureless, carbonaceous mass, corresponding to the coal-seam. On this are the last-fallen leaves, not yet disorganized, and the still-growing vegetation. Now, imagine this overwhelmed and buried by mud or sand, the whole subjected to powerful pressure, and a slow subsequent process of bituminization; and we have a complete reproduction of the phenomena of a coal-seam with its accompanying underclay filled with roots, and its black shale filled with leaf and branch impressions.

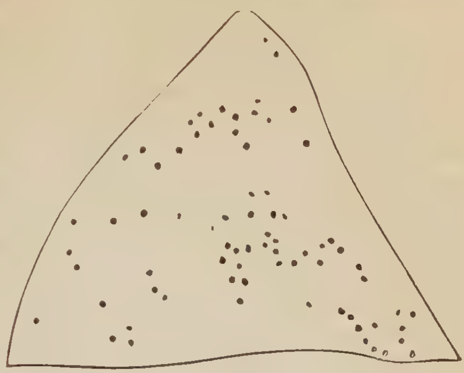


FIG. 507.—Ground-Plan of a Fossil Forest, Parkfield Colliery.

2. *Coal has been accumulated at the mouths of rivers*, and therefore in localities subject to floods by the river and incursions by the sea. It is otherwise impossible to account for the clays and sands (often inclosing drift-timber), and limestones, interstratified with the coal. The phenomena of an *individual seam* prove the accumulation by growth *in situ;* the general phenomena of a *coal-basin*, with its succession of strata, prove that this took place at the mouths of rivers. Thus, the field of discussion is narrowed to very small limits.

We conclude, therefore, that coal has been accumulated in extensive peat-swamps at the mouths of great rivers, and therefore subject to occasional floodings by the river, and inundations by the sea. That pure peat may accumulate under these circumstances, is sufficiently proved by the fact mentioned by Lyell, that over large tracts of ground in the river-swamp and delta of the Mississippi pure peat is now forming, in spite of the annual floods; the sediments being all stopped by the thick jungle-growth surrounding these spots, and deposited on the margins, while only pure water reaches the interior portions.[1]

But if coal has indeed been formed at the mouths of great rivers, we ought to find at least something analogous to a coal-field in sections of great river-deltas. And so, indeed, we do. We have seen (p. 130) that a great river-delta, like that of the Mississippi or the Ganges, consists of alternate layers of river-sediments (sands and clays) and marine sediments (limestones), with thin layers of peaty matter, and old forest-

[1] Lyell, "Elements of Geology," p. 488.

grounds with stumps and roots. It is, in other words, a coal-field, though an imperfect one, in the process of formation. It will be remembered, also, that we accounted for this alternation, not by oscillations, but by the operation of two opposing forces, one depressing (subsidence), the other up-building (river-deposit), with varying success. When the up-building by river-deposit prevailed, the area was reclaimed, and became covered with thick jungle vegetation; when the subsidence prevailed, it was again covered with water, and buried in river-sediments, etc. Now and then, when the subsidence was unusually great, the sea invaded the same area, and limestone was formed. It is substantially in this way that coal-fields were probably formed.

Application of the Theory to the American Coal-Fields: *a.* **Appalachian Coal-Field.**—A glance at the map (p. 289) will show that, during Carboniferous times, there was high land to the north, east, and west of this field, and the black area, representing the Coal-measures, was then a trough, into which, therefore, drained rivers from every side except the south. This trough was sometimes a coal-swamp, sometimes a lake emptying southward, sometimes an arm of the sea connecting with the ocean southward. When it was a coal-marsh, a coal-seam was formed; when a lake, sands and clays were deposited by the rivers; when an arm of the sea, marine deposits—limestones—were formed.

This alternation of conditions we explain as follows: There were three forces at work on this area: 1. A general continental *upheaval*, affecting this along with all other parts of the continent; 2. An *up-building* by sedimentary deposit; 3. A *local subsidence*. The evidence of all these is complete. The continental upheaval, as we have already seen, was unceasing throughout the *previous* periods, and, as we shall see, continued throughout the subsequent periods. The up-building by sediments and the *pari passu* subsidence are as clearly marked as in deltas of the present day, by *shore-marks*, by *shallow-water* fossils, and especially by *forest-grounds* repeated through several thousand feet of vertical thickness. The existence of these three forces, therefore, is not a doubtful hypothesis. Now, the first two would tend to *reclaim*, the third to *submerge*, the area. When the reclaiming forces predominated, the area became swamp-land, and covered with coal vegetation, and the river-water, strained through the thick growth, slowly went southward by a kind of seepage. When the submerging forces predominated, the area became a lake, and sediments in great quantities were brought down by the rivers. It is possible, perhaps probable, that correlative with the more rapid local subsidence which formed the lake there was also a more rapid elevation of the high lands on all sides, producing more torrential river-currents and greater sedimentary deposits. Now and then, at long intervals, the subsidence would bring the area below sea-level, and would thus form an interior sea, or mediterranean.

During such times, limestones would be formed, and marine animals would be imbedded as fossils.

b. **Western Coal-Fields.**—The *Central* and *Western* coal-fields may be regarded as *one*, having been subsequently separated by denudation. This immensely extensive field *may* have been, like the Appalachian, a hollow surrounded on all sides by higher land. If so, the western land has since been submerged, and covered by more recent deposits. Or it may have been an extensive jungly flat, bordering a western sea, with many small rivers with inosculating deltas, flowing westward and seeping through the thick, marshy vegetation. There were here far less mechanical sediments, because less high land, and far more marine deposits, because there was a larger and opener sea; but, in other respects, the process may be regarded as similar.

Appalachian Revolution.—This state of oscillation and incertitude was cut short by the Appalachian revolution. At the end of the Coal period, the sediments which had been so long accumulating in the Appalachian region, until their aggregate thickness had now reached 40,000 feet, at last yielded to the horizontal pressure produced by interior contraction of the earth (p. 262), and were crumpled, and mashed, and thickened up into the Appalachian chain. At the same time the Western coal-swamps were upheaved sufficiently to become permanent dry land. This revolution closed the Carboniferous age and the Palæozoic era.

Estimate of Time.

We have said (p. 275) that it is important that the mind become familiarized with the idea of the immense time necessary to explain geological phenomena. We therefore embrace this opportunity to make a rough estimate of the Coal period. The estimate may be made either by taking the whole amount of *coal* in a coal-field as the thing to be measured, and the *rate* at which vigorous vegetation now makes organic matter as the measuring-rod; or else by taking the whole *amount of sediments* in a coal-basin as the thing to be measured, and the *rate* of accumulation of sediments by large rivers as the measuring-rod. We will give both, though the latter is probably the more reliable.

1. **From Aggregate Amount of Coal.**—A vigorous vegetation—as, for example, an average field-crop or a thick forest—makes about 2,000 pounds of dried organic matter per annum per acre, or 200,000 pounds or 100 tons per century.[1] But 100 tons of vegetable matter pressed to the specific gravity of coal (1.4), and spread over an acre, would make a layer less than two-thirds of an inch in thickness. But, according to Bischof, vegetable matter in changing to coal loses, on an average, four-fifths of its weight by the escape of CO_2, CH_4, and H_2O (p. 357), only

[1] Recent researches considerably increase these numbers. *Nature*, vol. xvi., p. 211, 1877.

one-fifth remaining. Therefore, vigorous vegetation at present could make only about one-eighth of an inch of coal, specific gravity 1.4, per century. To make a layer one foot thick would require nearly 10,000 years. But the aggregate thickness in some coal-basins is 100 feet and even 150 feet (p. 350). This would require—the former near 1,000,000, the latter 1,400,000 years. It is probable, however, that coal vegetation was more vigorous than the present vegetation. Our measuring-rod may be too short; we will try the other method:

2. **From Amount of Sediment.**—We are indebted to Sir Charles Lyell for the following estimate of the time necessary to accumulate the Nova Scotia Coal-measures. This coal-field is selected because the evidences of river-sediments are very clear throughout. The area of this coal-basin is given on page 351 as 18,000 square miles; but the identity in character of portions now widely separated by seas—e. g., on Prince Edward's Island, Cape Breton, Magdalen Island, etc.—plainly shows that all these are parts of *one original field*, which could not have been less than 36,000 square miles. The thickness at South Joggins is 13,000 feet. At Pictou, 100 miles distant, it is nearly as great. We shall certainly not err on the side of excess, therefore, if we take the average thickness over the whole area as 7,500 feet. This would give the cubic contents of the original delta deposit as about 51,000 cubic miles. Now, the Mississippi River, according to Humphrey and Abbot, carries to its delta annually sediment enough to cover a square mile 268 feet deep, or nearly exactly *one-twentieth of a cubic mile.* Therefore, to accumulate the mass of sediment mentioned above would take the Mississippi about 1,000,000 years.

It may be objected to this estimate that it is founded on a particular theory of the accumulation of the Coal-measures. The answer to this is plain. Any other mode would only extend the time, for this mode is more rapid than any other. Again, it may be objected that we have evidence of a very rapid accumulation in stumps and logs and erect trunks, either bituminized or petrified, and which, therefore, must have been completely buried before they could decay. The answer is, that these are only examples of *local* rapid deposit, and do not at all affect the general result. Precisely the same happens now in river-deltas. Again, it may be objected that the agencies of Nature were far more energetic then than now. This objection has already been answered on page 275.

We, therefore, return to our estimate with increased confidence that it is far within limits. But the Coal period, as already said (p. 346), is not more than one-thirtieth of the recorded history of the earth; beyond which, again, lies the *infinite abyss of the unrecorded.*

Physical Geography and Climate of the Coal Period.

Physical Geography.—In the eastern part of the American Continent the area of land during this period is approximately shown in the map (p. 289). It included the Laurentian, the Silurian, and Devonian areas, during the whole age. In the sub-Carboniferous period the sub-Carboniferous and Carboniferous areas were covered by the sea, but in the Carboniferous period proper the sub-Carboniferous area was land, and the Carboniferous area, as already seen, was in an uncertain state, sometimes above and sometimes below the sea-level. It is probable, also, that the *Eastern border-land* extended then much beyond the line of the Tertiary deposits (*see* map, p. 289), perhaps beyond the present coast-line, and was partly submerged in the elevation of the Appalachian chain, at the end of the Coal period.

In the Rocky Mountain region there were considerable bodies of land, mainly in the Basin region, but their limits are not accurately known.

Again, it is almost certain that all the lands were comparatively low. None of the great mountain-chains of the continent were yet formed. It is also probable that the same was true of the other continents. Nearly all the high mountain-chains are either more recent in their *origin*, or else in their principal *growth*. In general terms, then, the lands were smaller and lower, and the conditions more oceanic, than at present.

Climate.—The climate of the Coal period was undoubtedly characterized by greater *warmth*, *humidity*, *uniformity*, and a more highly *carbonated condition* of the atmosphere, than now obtain. Most of these characteristics, if not all, are indicated by the nature of the vegetation:

1. The *warmth* is shown by the existence of a tropical or ultra-tropical vegetation. Of the present flora of Great Britain about one-thirty-fifth are Ferns, and none of these Tree-ferns. Of the Coal flora of Great Britain about one-half were Ferns, and many of these Tree-ferns. At present in all Europe there are not more than sixty known species of Ferns: in European Coal-measures there are nearly 350[1] species, and these are certainly but a fraction of the actual number then existing. That this indicates a tropical climate is shown by the fact that out of 1,500 species of living Ferns known twenty years ago, 1,200, or four-fifths, were tropical species. The number of known living Ferns is now about 3,000,[2] but the proportion of tropical species is still probably the same. Even in the tropics, however, the proportion of Ferns is far less than in Great Britain during the Coal period. Again, Tree-ferns, arborescent Lycopods, Cycads, and Araucarian Conifers, are now wholly con-

[1] Lesquereux. [2] *Nature*, August, 1876.

fined to tropical or sub-tropical regions. The prevalence of these tropical families and their immense size, compared with their congeners of the present day, would seem to indicate not only tropical but *ultra*-tropical conditions. And these conditions prevailed not only in the United States and Europe, but northward to 75° north latitude; for *in Mellville Island have been found coal-strata containing Tree-ferns, gigantic Lycopods, Calamites*, etc.

2. The *humidity* is indicated by the fact that Tree-ferns and arborescent Lycopods are most abundant now on islands in the midst of the ocean; and further by the great extent of the Coal swamps, and perhaps also by the general *succulence* of, or the predominance of cellular tissue in, the plants of that period.

3. The *uniformity* is proved by the great resemblance and often identity of the species in the most widely-separated regions. According to Lesquereux, out of 434 American and 440 European species, 176 are common, and the remainder far less diverse in character than the species of the two floræ at present. Again, in all latitudes, from the tropics to 75° north latitude, Coal species are extremely similar. Such uniformity of vegetation shows a remarkable uniformity of climate. From the earliest times until the present there has been probably a gradual evolution of continents—a gradual differentiation of land and water, a consequent differentiation of climates, and a corresponding differentiation of faunæ and floræ.

4. The *carbonated condition* of the atmosphere is proved by the large quantity of carbon laid up in the form of coal, the whole of which was withdrawn from the atmosphere in the form of *carbonic acid.* It is also indicated by the nature and the luxuriance of the vegetation. The proportion of carbonic acid in the atmosphere is now about $\frac{1}{20}$ per cent. ($\frac{1}{2000}$). Now, since carbonic acid is the necessary food of plants, it is natural to expect that up to a certain limit the increase of atmospheric carbonic acid would increase the luxuriance of vegetation. Experiments prove that this is *true for vascular Cryptogams*, but not for Phænogams.

We may therefore picture to ourselves the climate of this period as *warm*, *moist*, *uniform*, *stagnant* (for currents of air are determined by *difference* of temperature), and *stifling*, from the abundance of carbonic acid. Such physical conditions are extremely favorable to vegetation, but unfavorable to the higher forms of animal life.

Cause of this Climate.—The *moisture* and *uniformity* were the necessary result of the physical geography already given. They were due to the wide extent of ocean and the absence of large continents and high mountains. High mountains are the precipitating points for the atmosphere—points through which it discharges its superabundant moisture. As these did not exist, the atmosphere was always highly

charged. The prevalence of the ocean also, as is well known, produces uniformity.

The greater *warmth* of *high latitudes* is partly explained by the *uniformity*. But there is good reason to believe that there was then a higher *mean temperature* than now exists. This was probably due to the *constitution of the atmosphere*. This may be shown as follows:

The surface-temperature of the earth is now almost wholly due to *external*, not to internal, causes. It has been calculated that only one-twentieth of a degree Fahr. is now due to the latter cause. In going downward, the heat increases about 1° Fahr. for every 50 to 60 feet, i. e., the *internal* heat for every 50 feet of depth increases twenty times the surface temperature. Now, it has been shown by Fourier and Hopkins that the same would be true whatever be the surface-temperature from internal causes. For example, if the surface-temperature from internal causes be 1°, then for every fifty feet of depth the interior heat would increase 20°. If the surface-temperature from internal causes be 10°, then for every 50 feet of depth the interior heat would increase 200°—a condition of things entirely inconsistent with the growth of plants, since all the springs would be boiling. We cannot, therefore, attribute, as many have done, even a few degrees' increase of mean temperature to causes interior to the earth. In fact, it seems almost certain that during the whole recorded history of the earth, i. e., during the time it has been inhabited by organisms, the surface-temperature of the earth has been almost wholly due to external causes. Now, the composition of the atmosphere is an external cause, which greatly affects the surface-temperature, but which has hitherto been almost wholly neglected. The thorough explanation of this point will require some discussion of the properties of transparent media in relation to light and heat.

Many bodies which are transparent to light are opaque to heat. Such bodies, however, will freely transmit heat, if the heat be accompanied with intense light. It is as if the light carried the heat through with it. Heat thus associated with light is sometimes called *light-heat*, while that which is not thus associated is called *dark heat*. Now, the bodies spoken of are *transparent* to light-heat, but *opaque* to dark heat. Glass is such a body. If a pane of glass be held between the face and the *sun*, the heat passes freely and burns the face, but the same pane would act as a *partial* screen before a *fire*, and as a *perfect* screen before a hot, but not incandescent, *cannon-ball*.

It is in this way we explain the fact that a glass greenhouse, even in the coldest sunshiny winter's day, becomes insupportably warm if shut up. The sun-light and heat pass freely through the glass, and heat the ground, the benches, the flower-pots; but the light-heat thereby becomes converted into dark heat, and thus is *imprisoned* within.

Now, the *earth and its atmosphere are such a greeenhouse.* The light-heat passes readily through, warms the ground, changes into dark heat, and is in a measure imprisoned by the partial opacity of the atmosphere to this kind of heat. The atmosphere is a kind of blanket put about the earth to keep it warm. So much has long been recognized. But Tyndall has shown[1] that the property of opacity to dark heat in the case of the atmosphere is due wholly to the small quantity of carbonic acid and aqueous vapor present; that oxygen and nitrogen are transparent to dark heat, and, therefore, if the atmosphere consisted only of these two gases, it would not be heated by radiation from the earth, and the ground would lose all its heat by radiation during the night, and become intensely cold like space. In other words, the blanket put about the earth to keep it warm is woven of carbonic acid and aqueous vapor.

Now, we have seen that during the Coal period *the quantity of carbonic acid and aqueous vapor* in the air *was far greater* than now. The atmosphere was then a *double blanket*, and therefore kept the young earth much warmer. We believe that Prof. T. S. Hunt[2] was the first to apply this discovery of Tyndall to the explanation of the climate of the Coal period. E. B. Hunt had previously attributed it to greater density of the air (Dana, "Manual," p. 353); but this is a wholly different principle.[3]

Thus the physical geography explains the humidity and uniformity, and the greater humidity and the carbonic acid explain the greater mean temperature. But there is still the carbonic acid to be accounted for.

The more *highly-carbonated condition* of the atmosphere must be attributed to the original constitution of the air. All carbonic-acid-producing causes, such as animal respiration, combustion, general decay of organic matter, volcanoes, carbonated springs, etc., only *return* to the air what has been previously taken from it. There can be no doubt that all the carbon in the world, whether in the form of organic matter, or of coal, or of bitumen, or of carbonates, existed once as carbonic acid in the air, and has been progressively withdrawn. First immense quantities were withdrawn and fixed as carbonates, especially as carbonate of lime (limestone), and the air correspondingly purified. Again, immense quantities were withdrawn by the luxuriant vegetation of the Coal period, and fixed as *coal.* In this latter method of withdrawal the oxygen of the carbonic acid is returned, and the oxygenation of the air is in-

[1] "Proceedings of the Royal Society," vol. xi., p. 100; *American Journal*, second series, vol. xxxvi., p. 99.

[2] "Chemical and Geological Essays," p. 42.

[3] According to Buff, "Archives des Sciences," vol. lvii., p. 293, the opacity to dark heat of carbonic acid and aqueous vapor has been greatly exaggerated by Tyndall.

creased. We shall see hereafter that the process of purification did not cease with the Coal period ; for large quantities were again withdrawn and laid down as coal and lignite in the Jurassic, the Cretaceous, and Tertiary periods. There can be no doubt that this progressive purification of the air, by the withdrawal of superabundant carbonic acid and returning the pure oxygen, fitted it for the purposes of higher and higher animals.

Iron-Ore of the Coal-Measures.

We have already stated that the Coal-measures consist of alternating layers of sandstones, shales, and limestones, containing seams of *coal* and bands of *iron-ore.* We have already discussed the mode of *occurrence*, the *varieties*, and the *theory* of accumulation of the *coal.* We come now to discuss the same points in regard to the *iron-ore.*

Mode of Occurrence.—The mode of occurrence of iron-ore is, in many respects, like that of coal. Like coal, it is found in seams, which vary in thickness from a fraction of an inch to forty or fifty feet. Like coal, these very thick seams are apt to be impure, being largely mixed with clay. Seams pure enough to work profitably are seldom more than three or four feet thick. Like coal, the seams are repeated many times in the same section (Fig. 433, p. 347), but without any discoverable order of succession. Like coal, the seam is usually *underlaid by clay.*

Kinds of Ore.—The form of iron-ore found in all strata, except those containing coal, is usually *ferric oxide*, either hydrated (brown hematite—limonite), or anhydrous (red hematite), or else magnetic oxide ; but in the Coal-measures of this period, and in the Coal-measures of every other period—i. e., in *all strata containing coal*, the iron is in the form of *ferrous carbonate.* This is usually mixed with clay, and therefore called *clay iron-stone.* It is often nodular and mammillated, and called *kidney iron-ore.* Sometimes it is mixed intimately with carbonaceous matter, and is called *black-band ore.* This last very valuable ore is found in Pennsylvania, Ohio, and in Scotland.

The importance of the association of coal and iron in the same strata cannot be over-estimated. For this reason, the raising of coal and the manufacture of iron are conducted in connection with each other, and the smelting-furnaces are often situated at the mouths of the coal-mines. It is easy to understand, therefore, why Great Britain, the greatest coal-producing country in the world, should be also the greatest iron-producing country. Nearly all the iron-ore worked in Great Britain is taken from her coal-measures. In this country, much iron is made from the iron carbonates of the coal-measures, but much also from the peroxide ores found elsewhere, especially in Laurentian strata (p. 284).

The following table gives a comparative view of the annual iron-production, in tons, of the principal iron-producing countries of the world. It will be seen that Great Britain makes about half the iron of

the world. The rapid increase in the production of this great agent of civilization is also seen.

IRON.	1845.	1856.	1864.	1871.	1873.	1880.
Great Britain.....	2,200,000	3,500,000	5,000,000	5,667,000	6,566,000	7,741,000
United States.....	502,000	1,000,000	1,200,000	....	2,560,000	4,295,000
France	450,000	....	1,217,000	....	1,381,000	....
Germany.........	....	....	....	1,664,000	....	....
World..........	....	7,000,000	....	....	14,485,000	....

Theory of the Accumulation of the Iron-Ore of the Coal-Measures. —We have already explained (p. 136) how iron-ore is *now* accumulated by the agency of decaying organic matter. We have also shown that if the organic matter is consumed in doing the work of accumulation, the iron-ore is left in the form of iron peroxide ; but, if it is accumulated in the presence of excess of organic matter, it retains the form of ferrous carbonate. We will now give additional evidence, taken from the occurrence of iron ore in the strata of the earth, that the same agency has accomplished the same results in all geological times.

1. Immense beds of iron-ore are found in the strata of all geological ages ; but, wherever we find them, we find also associated a corresponding amount of strata, decolorized or leached of their iron coloring-matter. Contrarily, where we usually find the rocks extensively *red*, we find also an absence of valuable beds of iron-ore. We are thus led to conclude that the *iron-ore* of iron-beds *has been washed out of the strata*, which are thereby left in a decolorized condition.

2. That this has been done by the agency of organic matter is shown by the fact that, wherever we find evidences of organic matter, whether in the form of *fossils* or of *coal*, we find the sandstones and shales are white or gray—i. e., leached of coloring-matter. Conversely, red rocks are usually *barren* of *fossils* or of *coal*. For example, all the sandstones of the coal-measures, or of all other strata containing coal, are *gray*, while the Old Red sandstone below the coal, and the New Red sandstone above the coal, and, in fact, all red sandstones, are very poor in fossils or evidences of organic matter of any kind. Thus, evidences of organic matter, and the decoloring of the strata, and the accumulation of iron-ore, are closely associated as cause and effect.

3. In all the strata, whether older or newer, in which there is no coal, i. e., in which there is no excess of organic matter in a state of change, the iron-ore is peroxide (*ferric* oxide) ; while in coal-measures of all periods, whether Carboniferous, or Jurassic, or Cretaceous, or Tertiary, or in all cases where there is organic matter in excess in a state of change (not graphite), the iron-ore is in the form of carbonate protoxide, or *ferrous* carbonate ($FeCO_3$).

Therefore, we conclude that both *now* and *always* iron-ore is, and has been, accumulated by organic agency; again, that both now and always there are, and have been, three conditions of iron-ore, each associated with the absence or presence in smaller or larger quantities of changing organic matter: 1. It may be universally diffused as a coloring-matter of rocks and soils, and unavailable for industries; in this case there has been no organic matter to leach it out and accumulate it. 2. It may be accumulated as ferric oxide; in this case there has been organic matter only sufficient to do the work of accumulation, and was all consumed in doing that work. 3. It may be accumulated as ferrous carbonate; in this case there is excess of organic matter, usually in the form of *coal.*

This much is certain; but, as to the exact mode and time of the leaching and accumulation, there is some difference of opinion. There are two ways in which the accumulation may have occurred: It may have accumulated *in the coal-marshes during the Coal period*, being at that time leached out of the surrounding soils, which were therefore left in a decolorized condition, and in this condition subsequently washed down as sediments into the coal-marshes. Or, it may have been brought down as the coloring-matter of red sands and clays; and *afterward*, perhaps after the Coal period, leached out by percolating waters containing organic matter from the coal-beds, carried downward until stopped by an impervious clay-stratum, and accumulated there. The former mode is the more probable.[1]

But, in any case, organic matter has been the agent; and, therefore, in this case, as in all other cases, iron-ore is the *sign* of organic matter, and the *measure* of the amount of organic matter consumed in its accumulation. There are, therefore, three signs of the previous existence of organisms used by geologists: they are *coal, iron-ore*, and *fossils.*

We cannot dismiss this subject without making one passing reflection suggested by the mention of these three signs of life:

The organic kingdom is so much matter taken from the atmosphere, embodied for a brief space in individual living forms, to be again dissolved by death, and returned to the atmosphere whence it came. The same material is again taken by the next generation, embodied, and again returned at its death. The same small quantity of matter in the atmosphere is embodied and disembodied, again embodied and disembodied, and thus worked over and over again by constant circulation thousands, yea, millions of times, in the history of the earth. Now, in this constant circulation of the elements of organic matter, besides the work done in the fact of circulation itself, viz., the wonderful but fleeting phenomena of vegetable, animal, yea, of human life, there was another work, the results of which accumulated from age to age—

[1] Bischof, *Chemical Geology*, vol. i., p. 315.

a work, too, of the greatest importance to the well-being of the human race. *A portion* of this circulating matter, in its course downward from the organic to the mineral kingdom, *stopped half-way*, and was accumulated as great beds of *coal*—reservoirs of stored force. As circulating water descending seaward is stopped and stored in reservoirs to complete its descent under the control of man, and do his work, so circulating organic matter descending is stopped and stored, and is now completing its descent under the control of man, and doing his work, and thus becomes the great agent of modern civilization.

A second portion of circulating organic elements *completes* its descent, but in doing so accumulates iron-ore, the second great civilizer of the human race.

A third portion also completes its descent, but accumulates neither coal nor iron-ore; but it accomplishes a work far more subtile and beautiful than either of the others. As each particle of organic matter returns to the atmosphere, it compels a particle of mineral matter to take its place, thus completely reproducing its form and structure. Thus fossils are formed, and thus is the history of the organic kingdom self-recorded. Thus, while the other two portions have subserved the material wants of man, this portion has subserved his higher intellectual wants.

Bitumen and Petroleum.

The origin of bitumen and petroleum is so closely connected with that of coal, that although not confined to, nor even found principally in, the Coal-measures, the subject is best taken up in this connection.

It is well known that coal or any organic matter, by suitable distillation, may be broken up into a great variety of products: some solid, as *coal-pitch;* some tarry, as *coal-tar;* some liquid, as *coal-oil;* some volatile, as *coal-naphtha;* and some gaseous, as *coal-gas.* Now, we find collected, in fissures beneath the earth, or issuing from its surface, a very similar series of products: some solid, as *asphalt;* some tarry, as *bitumen;* some liquid, as *petroleum;* some volatile, as *rock-naphtha;* and some gaseous, as *marsh-gas and carbonic acid* of burning springs. There can be no doubt that these also *are of organic origin.*

Geological Relations.—Bitumen and petroleum are found in all fossiliferous rocks, from the lowest Silurian to the uppermost Tertiary, under certain conditions, among which are the local abundance of organisms from which these substances are formed, and the absence of great metamorphism. The *signs* of their presence in any locality are iridescent scums on the water of springs (oil-show), and the issuing of combustible gases (burning springs). In regard to the first sign, it must be remembered that iridescent scums are produced by many other substances besides petroleum. The second sign is considered the best, although combustible gases may issue from decomposing organic matter of any kind,

or from coal. Some of the burning springs in the oil-region of Kentucky are said to produce a flame twenty to thirty feet long. It is a curious fact that petroleum is often *associated with salt*. It is so in Pennsylvania, in Virginia, and in many other localities.

Oil-Formations.—I have said that petroleum and bitumen are found in all fossiliferous formations, but in each country there are certain formations where it especially abounds: in Europe it is found principally in the Tertiary; in Eastern United States it is found almost wholly in the Palæozoic, below the Coal-measures; in California it is found in the Tertiary.

Principal Oil-Horizons of the United States.—In Pennsylvania and Kentucky oil is found in the Upper Devonian; in Canada and Michigan, in the Lower Devonian; in Western Virginia it is found in the sub-Carboniferous; in Ohio, in Lower Coal-measures, though it probably originates below; in California it is found in Miocene Tertiary of the Coast Range, all the way from Los Angeles to Cape Mendocino. These have been called oil-horizons.

Laws of Interior Distribution.—The mode of interior distribution of petroleum and bitumen is similar to, yet different from, that of water. Like water, it occurs in *porous* strata and collected in fissures and cavities; like water and with water, it *issues* in hill-side springs; like water and with water, it *collects* in ordinary *wells*, or sometimes *spouts* in immense quantities from artesian wells. Some of the great spouting-wells of Pennsylvania, when first opened, yielded 3,000 bar-

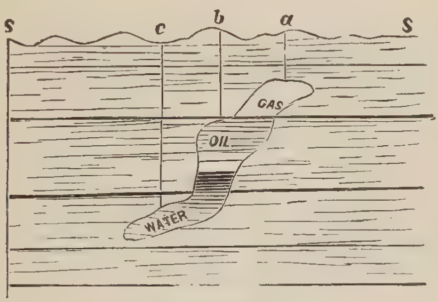


Fig. 508.

rels per day. But, unlike water, there is *no perennial large supply*; the accumulations of ages being exhausted in a few months or a few years. Unlike water, the *force of ejection* in great spouting-wells is not hydrostatic pressure, but the pressure of *elastic gases* generated from the petroleum. The great *spouting-wells*, being, therefore, the fortunate tappings of reservoirs which have been accumulating for millenniums in great fissures and cavities, are enormously productive, but

also rapidly exhausted. In the case of less productive but more permanent wells, the oil is contained in more numerous but smaller fissures and pores. In all cases of collection in large fissures and cavities, these

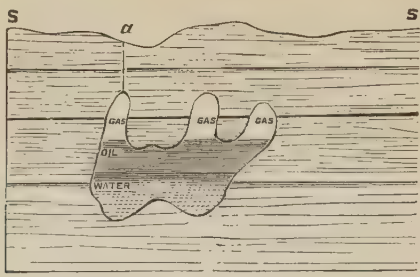


FIG. 509.

reservoirs are occupied also by water and gas ; and the three materials arrange themselves in the order of their relative specific gravities, as in Figs. 508 and 509.

These facts easily account for the many curious phenomena connected with oil-wells. Thus, if the well *a* (Fig. 508) taps the reservoir, only gas will escape, and oil and water can be gotten only by pump. But if the well be at *b*, oil will spout; and afterward, when the gas has escaped, oil and water may be pumped. If the well be at *c*, then water will spout first and afterward oil. If the cavity be irregular, with more than one chamber containing compressed gas (Fig. 509), and the well be at *a*, then gas will escape first, and afterward oil and water will spout.

Kinds of Rocks which bear Petroleum.—As already stated, petroleum, like water, is found principally in pores and fissures and cavities. The same kinds of rocks, therefore, which are water-bearing are also oil-bearing, viz., *limestones* and *sandstones*. In Canada it is found in limestone, in Pennsylvania in sandstone. The intervening shales are usually barren. In Pennsylvania there are three oil-bearing sandstones, separated by about 200 feet of intervening shales. If a well reaches the first sandstone without obtaining oil, the boring is continued to

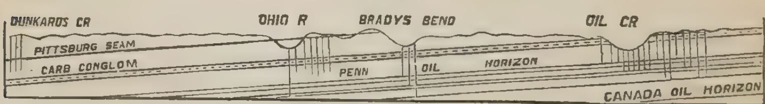


FIG. 510.

the second, or even to the third. Fig. 510 (taken from Lesley) represents a section through the Pennsylvania oil-regions, showing the three principal oil-horizons of the United States, viz., the Venango

County (Pennsylvania) horizon with its three sandstones; the Virginia sub-Carboniferous horizon above; and the Canada horizon below.

Petroleum (especially the lighter oils) is usually found only in horizontal or gently-folded strata, because strongly-folded and crumpled strata are always metamorphic, and the heat which produced metamorphism has also concreted the oil into bitumen or asphalt. Also the outcropping of the edges of highly-inclined strata favors the escape of gas and the concretion of the oil. It is hardly probable, therefore, that a light oil will ever be found in the California oil-region.[1]

In gently-folded strata the most productive portions seem to be along a line of anticline; because there we may expect large fissures, and also, perhaps, because the oil working up on the surface of water is apt to accumulate under the saddles of the strata.

Origin of Petroleum and Bitumen.

We have seen that the whole petroleum and bitumen series may be made artificially by destructive distillation of coal. There seems also to be little doubt that certain organic matters at *ordinary* temperature, in presence of abundant moisture, and out of contact of air, will undergo a species of decomposition or fermentation by which an oily or tarry substance, similar to bitumen, is formed. In the interior of heaps of vegetable substance such bituminous matter is often found. Taking the composition of petroleum as C_nH_{2n}, the reaction by which it is formed from vegetable matter is expressed in the following:

$$\begin{array}{ll} \text{Cellulose} \ldots\ldots\ldots\ldots\ldots\ldots & C_{36}H_{60}O_{30} \\ \text{Subtract} \left\{ \begin{array}{c} 15CO_2 \\ 9CH_4 \end{array} \right\} \ldots\ldots\ldots\ldots & C_{24}H_{36}O_{30} \\ \hline & C_{12}H_{24} = \text{petroleum.} \end{array}$$

Or,

$$\begin{array}{ll} \text{Cellulose} \ldots\ldots\ldots\ldots\ldots\ldots & C_{36}H_{60}O_{30} \\ \text{Subtract} \left\{ \begin{array}{c} 12CO_2 \\ 6H_2O \end{array} \right\} \ldots\ldots\ldots\ldots & C_{12}H_{12}O_{30} \\ \hline & C_{24}H_{48} = \text{petroleum.} \end{array}$$

There are therefore two general theories of the origin of petroleum: one, that it is produced by the distillation at high temperature of bituminous coal by volcanic heat, the coal being left as anthracite; the other, that it is formed at ordinary temperature by a peculiar decomposition of certain organic matters. The evidence in favor of the first view is the similarity between the artificial and the natural series; the objection to it is that the occurrence of petroleum seems to have no necessary connection with the occurrence below of coal-seams, and also that petroleum is found mostly in strata which have not been subjected to any considerable heat.

[1] Some tolerably good oil has been found in California in metamorphic strata.

The argument for the other view is the fact that we actually find fossil cavities in solid limestone containing bitumen, evidently formed by decomposition of the animal matter. So, also, shales have been found in Scotland filled with fishes, which have changed into bitumen.

The most probable view seems to be that both coal and petroleum are formed from organic matter, but of different kinds and under slightly different conditions—that coal is formed from *terrestrial* vascular plants, in the presence of *fresh water*, while bitumen and petroleum are formed from more *perishable cellular* plants and animals, in the presence of *salt-water*. We have already noticed the frequent association of petroleum and salt.

Origin of Varieties.—However formed, there can be no doubt that the different varieties of this series are formed from one another by a subsequent process. It is certain that from all varieties CH_4 is constantly passing off, and that the result of this is a slow consolidation. By this process light oil is changed into heavy oil, heavy oil into bitumen, and bitumen into asphalt. Some of the grandest fissure-reservoirs of oil have thus been changed into solid asphalt. In the upper barren Coal-measures of West Virginia there is a vein of asphalt four feet thick, over 3,000 feet long, and of unknown depth. It fills a great fissure which breaks through the rocks nearly perpendicularly, and outcrops on the surface.

There are, therefore, two series of substances formed from organic matter, viz., the coal series and the oil series. In each series the proportion of carbon increases by subsequent change until, perhaps, pure carbon may be reached. In the coal series we have fat coal, bituminous coal, semi-anthracite, anthracite, and, finally, graphite. In the oil series we have light oil, heavy oil, bitumen, asphalt, probably jet, and possibly, finally, *diamond:* for Liebig has suggested that diamond is most probably formed by crystallization of carbon from a liquid hydro-carbon, in which the proportion of carbon is constantly increasing by loss of CH_4.

Area of Oil-bearing Strata in the Eastern United States.—The amount of oil in the United States is practically inexhaustible. The finding of great reservoirs, producing spouting-wells, has always been, and always will be, very uncertain ; but a moderate return for industry and capital is certain for an unlimited time. A large portion of the Palæozoic basin, including an area of about 200,000 square miles, is underlaid by rocks which are more or less oil-bearing. The eastern portion of the United States is the great oil-bearing, as it is the great coal-bearing, country of the world.

Fauna of the Carboniferous Age.

As heretofore, we will disregard the subdivisions, and treat of the fauna of the whole age, at least of sub-Carboniferous and Carboniferous, together. It must be borne in mind, however, that most of the lower marine animals mentioned are from the sub-Carboniferous, while most of

Fig. 511.

Fig. 512.

Fig. 513.

Figs. 511-513.—Carboniferous Corals: 511. Lithostrotion Californiense (after Meek). 512. Clisiophyllum Gabbi (after Meek). 513. *a*, Archimedes Wortheni (after Hall); *b*, Portion of same, enlarged to show structure.

the fresh water and land animals are from the Coal-measures. We can notice only what important families are going out, what important families are coming in, and a few which are very characteristic.

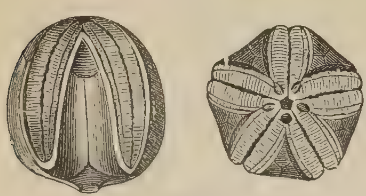


FIG. 514.

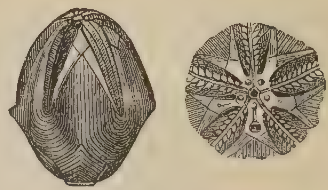


FIG. 515.

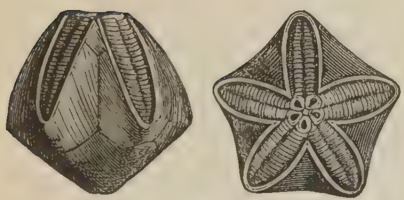


FIG. 516.

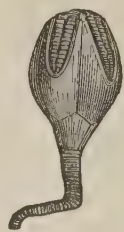


FIG. 517.

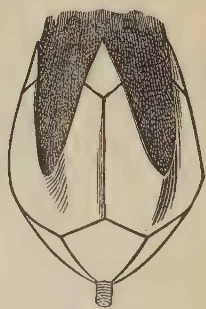


FIG. 517a.

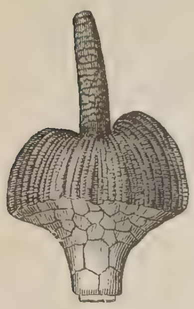


FIG. 518.

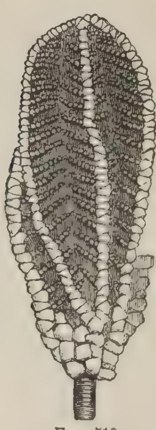


FIG. 519.

FIG. 520.

FIGS. 514-520.—ECHINODERMS OF THE CARBONIFEROUS AGE—*Blastids:* 514. Pentremites Burlingtoniensis (after Meek). 515. Pentremites gracilis (after Meek). 516. Pentremites cervinus (after Hall). 517. Pentremites pyriformis (after Hall). 517a. Pentremite restored (after Lütken). *Crinids:* 518. Batocrinus Chrystii (after Meek). 519. Scaphiocrinus scalaris (after Meek). 520. Forbesiocrinus Wortheni (after Meek).

Among *corals* the same general characteristic Palæozoic type (Quadripartita continues to prevail, though in greatly-diminished variety of families; for the Favositidæ and Halysitidæ have passed away, and

only the Cyathophylloids, or cup-corals, remain. The most beautiful and characteristic are the Columnar Lithostrotion (Fig. 511), a polyp-coral, and the curious corkscrew-like Archimedes (Fig. 513), a Bryozoan.

Among *Crinoids*, the *Cystids* no longer exist, for they passed out with the Silurian, but the *Blastids* and *Crinids* increase in number and

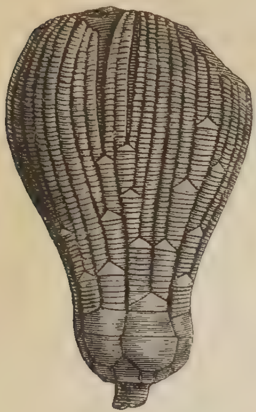


FIG. 521.

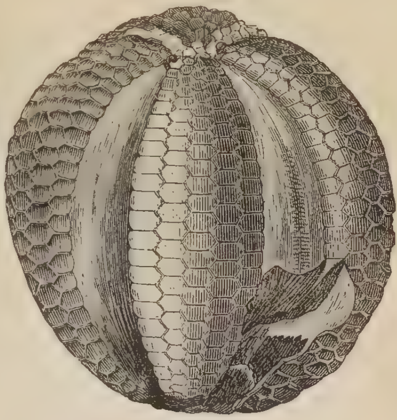


FIG. 522.

FIG. 523 *b*.

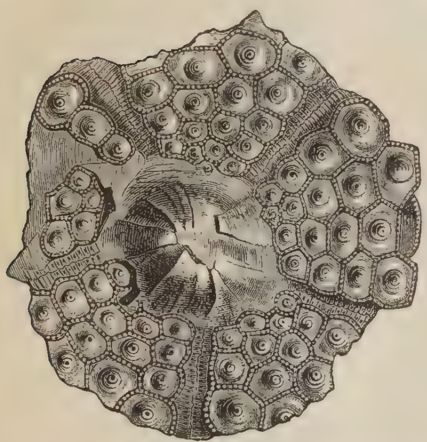


FIG. 523 *a*.

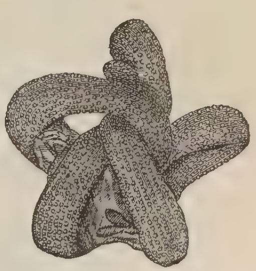


FIG. 524.

FIGS. 521-524. — ECHINODERMS OF THE CARBONIFEROUS AGE — *Crinid:* 521. Zeacrinus elegans (after Hall). *Echinoids and Asteroids:* 522. Oligoporus nobilis, × ½ (after Meek). 523. *a*, Archæocidaris Wortheni (after Hall); *b*, Spine of same, natural size. 524. Onychaster flexilis (after Meek)

beauty. Also, the free Echinoderms (Echinoids, and Asteroids) begin to be more abundant.

Among Brachiopods, the straight-hinged or square-shouldered kinds continue, but pass out almost wholly with this age.

Land and fresh-water shells, as might have been expected, are beginning to be found in great abundance in the Coal-measures. The genus *Pupa*, a land air-breathing gasteropod, and the genus *Cyclas*, a fresh-

a b

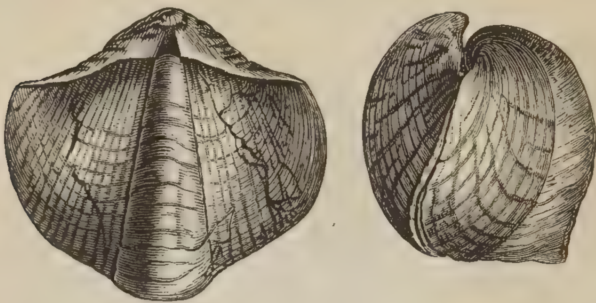


FIG. 525.

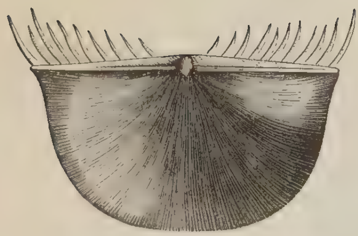


FIG. 526.

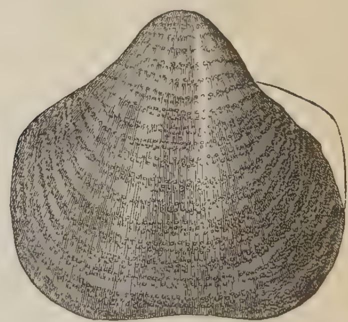


FIG. 527.

a b

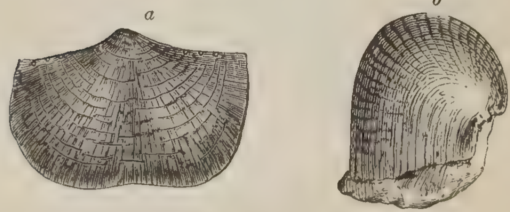


FIG. 528.

FIGS. 525–528.—CARBONIFEROUS BRACHIOPODS: 525. Spirifer plenus (after Hall); *a*, dorsal view; *b*, side view. 526. Chonetes Dalmaniana. 527. Productus punctatus (after Meek). 528. Productus mesialis (after Hall); *a*, ventral view; *b*, side-view.

water bivalve, and the genus *Cypris*, a little crustacean bivalve, all of which are still represented by living species, are found.

Of course, *marine* species, both Lamellibranchs and Gasteropods, are abundant. Some figures of these are given below.

FIG. 529.

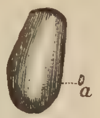


FIG. 530.

FIG. 531.

FIG. 532.

FIGS. 529–532.—CARBONIFEROUS LAND AND FRESH-WATER SHELLS: 529. Pupa vetusta (after Dawson)—a Land-Shell; *a*, natural size; *b*, enlarged. 530. Cypris (after Dawson); *a*, natural size. 531. Spirorbis (after Dawson); *a*, natural size. 532. Naiadites (after Dawson).

Among *Cephalopods*, Orthoceratites still continue, but in diminished number, variety, and size. *Goniatites*, introduced in the Devonian, also

FIG. 533.

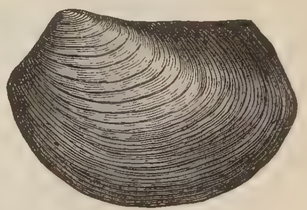


FIG. 534.

FIG. 535.

FIG. 536.

FIGS. 533–536.—CARBONIFEROUS LAMELLIBRANCHS (after Meek): 533. Solenomya anodontoides. 534. Allorisma ventricosa. 535. Allorisma pleuropistha. 536. Astartella Newberryi.

continue, but both may be said to pass out with this age, although a few seem to pass into the Lower Triassic.

Trilobites and *Eurypterids* also continue ready to disappear at the

Fig. 537.

Fig. 538.

Fig. 540.

Fig. 539.

Figs. 537–540.—Carboniferous Gasteropods (after Meek): 537. Macrocheilus Newberryi. 538. Pleurotomaria scitula. 539. Euomphalus subquadratus. 540. Bellerophon sublævis (after Hall).

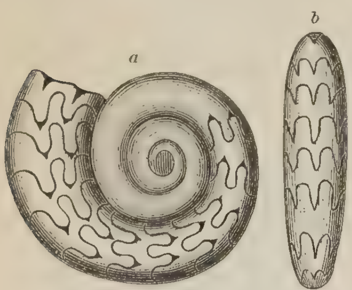


Fig. 541.

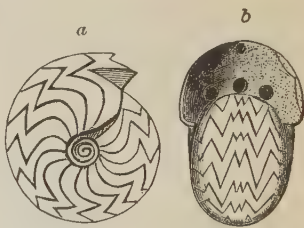


Fig. 542.

Figs. 541, 542.—Carboniferous Goniatites: 541. Goniatites Lyoni (after Meek); *a*, side-view; *b*, end-view. 542. Goniatites crenistria (European); *a*, side-view; *b*, end-view.

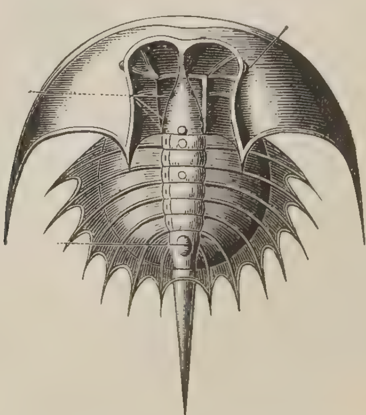


Fig. 543.—Carboniferous Crustacean: Euproöps Danæ (after Meek and Worthen).

end, but an advance in the Crustacean class is observed in the introduction here of *Limuloids* (king-crabs), Fig. 543, and of *Macrourans*—long-tailed Crustaceans (lobsters, crawfish, shrimps, etc.), Figs. 545–547.[1]

Insects now for the first time seem to be in considerable abundance and variety. Their appearance in connection with abundant land-vegetation seems natural. Nearly all the principal orders of insects are rep-

FIG. 544.

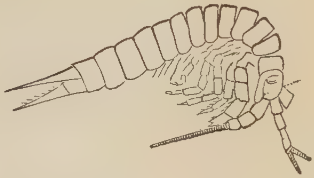


FIG. 545.

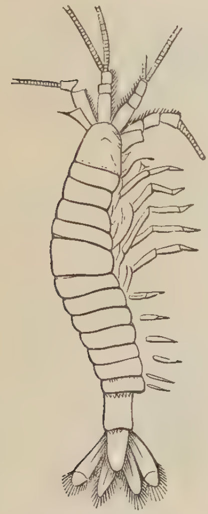


FIG. 546.

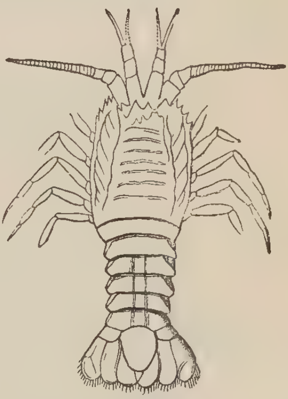


FIG. 547.

FIGS. 544–547.—CARBONIFEROUS CRUSTACEANS: 544. Phillipsia Lodiensis (after Meek). 545. Acanthotelson Stimpsoni (after Meek and Worthen). 546. Palæocarus typus (after Meek and Worthen). 547. Anthrapalæmon gracilis (after Meek and Worthen).

resented, viz., dragon-flies (Neuropters), Fig. 551; grasshoppers, cockroaches, etc. (Orthopters), Figs. 549 and 550; spiders and scorpions (Arachnids), Fig. 548; beetles (Coleopters) and centipedes (Myriapods), Figs. 552 and 553.[1] About thirty species have been described from the American Coal-measures, of which eight are Orthopters; eleven, Neuropters; four, Arachnids; and seven, Myriapods[1] (Scudder).

[1] See APPENDIX.

Vertebrates (Fishes).—The great Ganoids and Placoids continue in undiminished or even increased numbers, size, and variety. They are still the rulers of the seas. Of *Placoids*, one has been found with dorsal

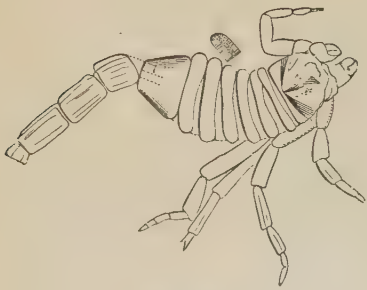


Fig. 548.

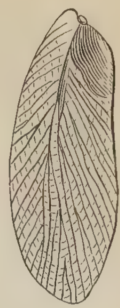


Fig. 549.

Fig. 550.

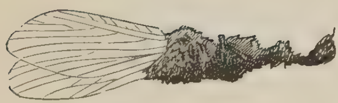


Fig. 551.

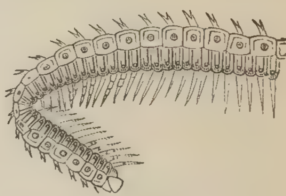


Fig. 552.

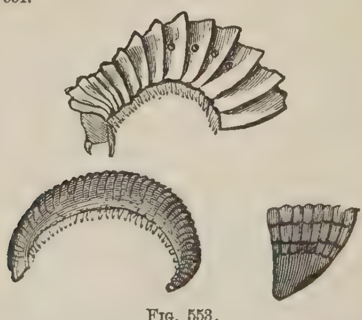


Fig. 553.

Figs. 548-553. Carboniferous Insects: 548. Eoscorpius carbonarius (after Meek and Worthen). 549. Blatta Maderæ, Wing-cases (after Lesquereux). 550. Blattina venusta, Wing-cases (after Lesquereux). 551. Miamia Danæ (after Scudder). 552. Euphoberia armigera (after Meek and Worthen). 553. Zylobius sigillariæ (after Dawson).

spine eighteen inches long, another with spine three inches broad and nine and a half inches long, although much of the point is broken off. Their teeth, too, are beginning to assume more of the character of true shark's-teeth. They are no longer wholly *Cestracionts* (Fig. 558), but also now *Hybodonts*, having teeth somewhat like modern sharks, but rounded on the edges (Figs. 560 and 561). Among *Ganoids*, the well-protected but sluggishly-moving *Placoderms* have passed away,

but the *Sauroids* continue in increased numbers and size. Bony, enameled *scales* of the Megalichthys and Holoptychius are found, two to three inches across; and jaws of the Holoptychius, a foot or more

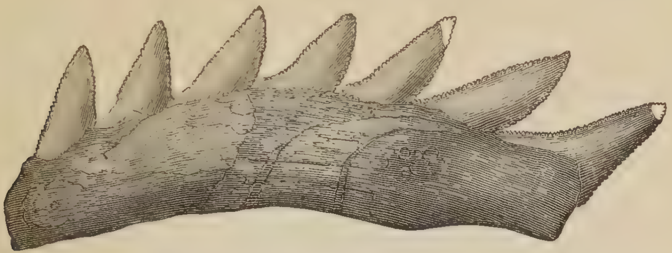


Fig. 554.

Fig. 555.

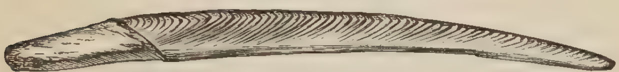


Fig. 556.

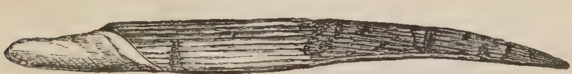


Fig. 557.

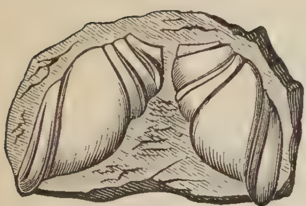
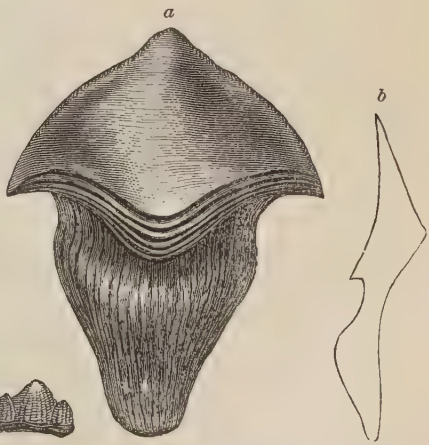


Fig. 558.



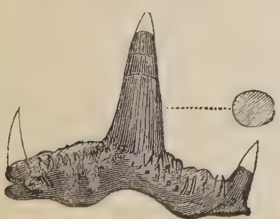


Fig. 560.

Fig. 561.

Fig. 559.

Figs. 554–561.—Carboniferous Fishes—*Placoids:* 554. Edestus minor (after Newberry). 555. Pleuracanthus—a Ray (after Nicholson). 556. Gyracanthus (after Nicholson). 557. Ctenacanthus (after Nicholson). 558. Cochliodus contortus. 559. Petalodus destructor (after Newberry). 560. Cladodus spinosus (after Newberry). 561. Orodus mammilare (after Newberry).

long, armed with Saurian teeth, two inches in length (Fig. 563). Also, as we approach the time for the appearance of Reptiles, some of these

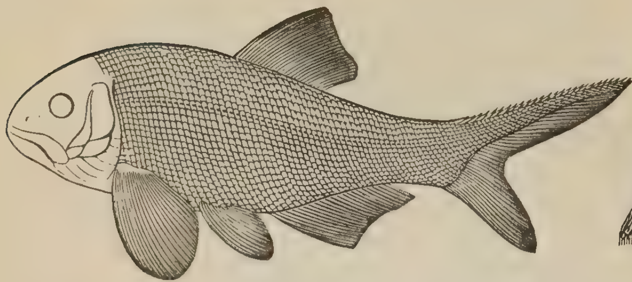


FIG. 562.

FIG. 563.

FIGS. 562, 563.—CARBONIFEROUS FISHES—*Ganoids:* 562. Amblypterus macropterus. 563. Tooth of Holoptychius Hibberti, natural size.

Sauroid fishes seem to become still more reptilian in character, while others become more *fish-like.*

Reptiles—Amphibians.—The first known appearance of the class of Reptiles on the earth was in this age: not yet, however, in as great numbers or size, or as high in the scale of organization, as in the next age. The reign of Reptiles had not yet commenced.

The class of Reptiles may be divided into two sub-classes, viz., True Reptiles and Amphibians. The Amphibians differ so greatly from other Reptiles, that they are now usually made a distinct class, intermediate between Fishes and True Reptiles. Of these two sub-classes *only the Amphibians are certainly known to have been represented in the Carboniferous*, although probably True Reptiles also existed in the last portion of this period. Again, Amphibians are subdivided into four orders, viz.: 1. Tailless Batrachians (*Anoura*), such as frogs, toads, etc.; 2. Tailed Batrachians (*Urodela*), such as tritons, salamanders, sirens, etc.; 3. The rare snake-like forms (*Ophiomorpha* or *Gymnophiona*); and 4. *Labyrinthodonts.* Of these, only the Labyrinthodonts were represented in the Carboniferous. The other three orders still exist, but the last has been long extinct. The Labyrinthodonts were very large, often gigantic, reptiles. They were most of them salamandriform, with long tail, weak limbs, and sluggish movement. Some were pisciform, and had paddles instead of feet.

We can only briefly describe a few representatives of the class, and draw some conclusions.

1. **Reptilian Footprints.**—In the sub-Carboniferous of Pennsylvania,

near Pottsville, have been found *tracks* of a four-footed, crawling animal (*Sauropus primævus*), having thick, fleshy feet about four inches long, and making a stride of about thirteen inches. The impression of a dragging tail is also visible. The surface of the slab on which the tracks are found is marked with distinct ripple-bars and rain-prints. "We thus learn," says Dana, "that there existed in the region about Pottsville, at that time, a mud-flat on the border of a body of water; that the flat was swept by wavelets, leaving ripple-marks; that the ripples were still fresh when a large amphibian walked across the place;

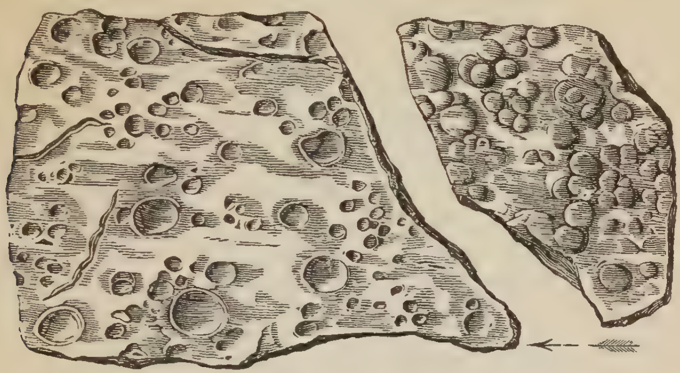


FIG. 564.—Fossil Rain-prints of the Coal Period.

that a brief shower of rain followed, dotting with its drops the half-dried mud; that the waters again flowed over the flat, making new deposits of detritus, and so buried the records."

Similar tracks have also been found in the Coal-measures of Pennsylvania, on a slab affected with *sun-cracks* (Fig. 565). The reptile had evidently walked on the cracked and half-dried mud at low tide. Tracks have also been found in the Coal-measures of Illinois, Indiana, Kansas, and Nova Scotia, and in the latter place beautiful specimens of rain-prints (Fig. 564).

There can be little doubt that the reptiles making the tracks mentioned above were *Labyrinthodonts.*

2. **Dendrerpeton.**—In the Coal-measures of Nova Scotia have been found quite a number of small reptiles, belonging to several genera. Among these one is especially interesting, on account of the conditions under which it seems to have been preserved. It is called the *Dendrerpeton*—tree-reptile—(Fig. 566), because it was found by Dawson and Lyell in sandstone, filling the hollow stump of a Sigillaria (Fig. 567), along with another small species of reptile, a number of land-shells —pupa, etc.—(Fig. 529, p. 397), and a myriapod (Fig. 553, p. 400).

The Sigillaria possessed a thick, strong bark, which was more resistant of decomposition than the cellular interior. Stumps of these trees are

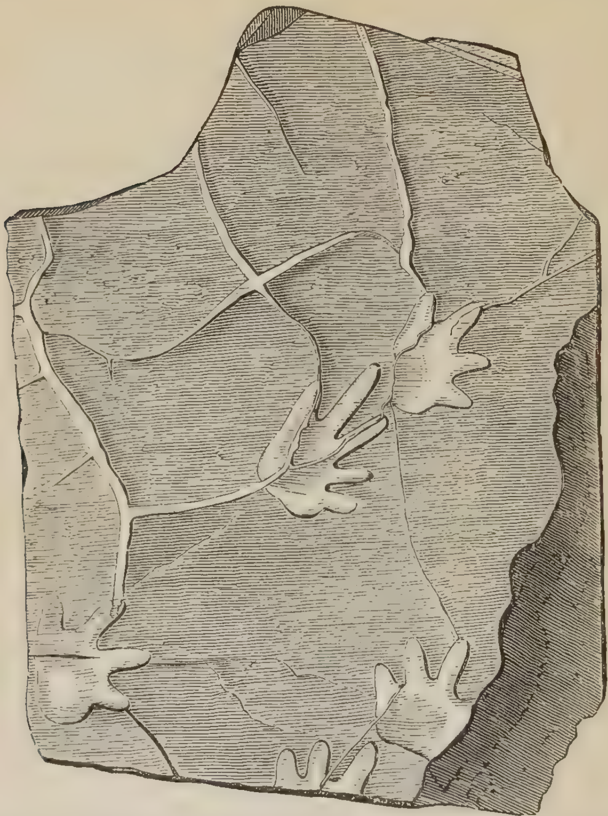


Fig. 565.—Slab of Sandstone with Reptilian Footprints, from Coal-measures of Pennsylvania; × ⅛.

often found, consisting only of coaly bark filled with sandstone, evidently deposited within the hollow. These sands are rich repositories

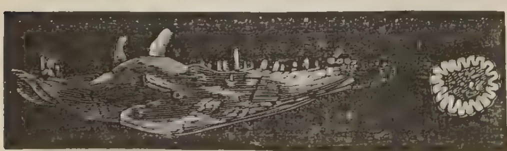


Fig. 566.—Jaw of Dendrerpeton Acadeanum, and Section of Tooth, enlarged (after Dawson).

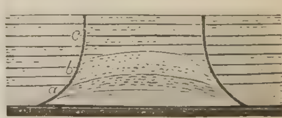


Fig. 567.—Section of Hollow Sigillaria Stump, filled with Sandstone (after Dawson).

of organic remains. We can easily imagine the circumstances under which the Dendrerpeton was preserved. A dead Sigillaria tree, rotted

to the base and only its hollow stump remaining, stood on the margin of a coal-swamp; river-floods filled the stump with sand; in the stump lived and perished a Dendrerpeton; or else the dead body of the reptile, together with shells and other organic remains, was floated into the hollow stump and buried there. This reptile was probably a Labyrinthodont, but with strong alliances with true reptiles, especially Lacertians.

3. Archegosaurus (*Primordial Saurian*).—In the Bavarian Coal-measures has been found the almost perfect skeleton of a reptile, about three and a half feet long, which combines in a remarkable degree the characters of *Amphibians* with those of *Ganoid Fishes.* It seems to have been a Labyrinthodont Amphibian, with general form and structure adapted for a purely aquatic life. It had, certainly in the early stages of its life, probably throughout life, both gills and lungs, and therefore, like all the Amphibians of the present day at this stage, or like Perennibranchiate Amphibians throughout life, breathed both air and water. The locomotive organs were paddles, adapted for swimming, not for walking. The body was covered with imbricated *ganoid scales* (Fig.

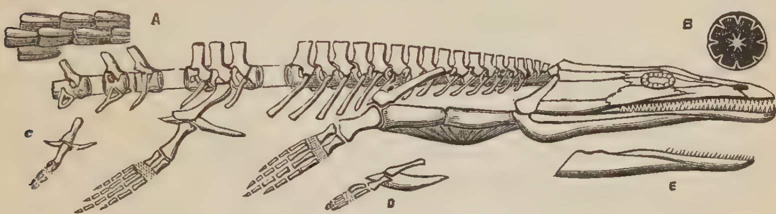


Fig. 568.—Archegosaurus.

568, *A*), and the head with *ganoid plates.* The structure of the teeth (*B*) was also ganoid. The bodies of the vertebræ were not ossified nor even cartilaginous, but retained the early, embryonic, fibrous condition of a *notochord.* It was apparently a connecting link between the lowest Perennibranchiate Amphibians and the Sauroid Fishes (Owen), with, perhaps, some alliances with the marine Saurians which afterward appeared. It was so distinct from other Labyrinthodonts that Prof. Owen puts it in a distinct order, which he calls *Ganocephala.* The skeleton of this animal is given above (Fig. 568), with the limbs (*C* and *D*) and jaw (*E*) of a Proteus—a perennibranchiate amphibian—for comparison.

4. Eosaurus.—In the Coal-measures of Nova Scotia, in 1861, Prof. Marsh found the vertebræ of what he thinks, with much reason, was a marine Saurian; an order which is largely developed in the Mesozoic. But as only the bodies of a few vertebræ have been found, and as the bi-concavity of these is the chief evidence of marine Saurian affinity, and as bi-concavity also exists among Labyrinthodonts, Huxley believes this was also a Labyrinthodont. There is, therefore, still some doubt as

to the true affinity of this animal, but the weight of evidence seems in favor of a marine Saurian. The size of some of the vertebræ was two and a half inches, indicating a reptile of gigantic dimensions.

Many other genera have been described by authors both in Europe

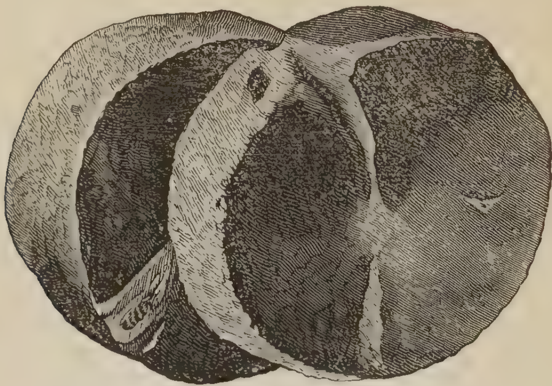


FIG. 569.—Two Vertebræ of Eosaurus Acadiensis (after Marsh).

and America. Among these, Baphetes, Raniceps, Hylerpeton, Hylonomus, and Amphibamus from America, and Anthracosaurus, Ophiderpeton, and Apateon from Europe, are best known. The Baphetes and the Anthracosaurus attained gigantic size.

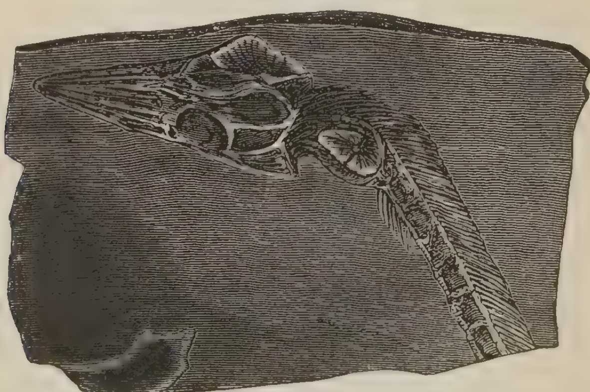


FIG. 570.—Ptyonius (after Cope).

Very recently a large number (thirty-four species referable to seventeen genera) of small Amphibians have been brought to light by the Ohio Survey, and described by Cope. These are all, or nearly all, Labyrinthodonts (*Stegocephali*, Cope). Some of them have the usual broad

heads of Amphibians, but a large number are remarkable for their long, limbless, snake-like forms and pointed heads. These are evidently among the lowest form of Amphibians, and have strong affinities also with Ganoid fishes. Figs. 570 and 571 represent two of the Ohio Amphibians.

Some General Observations on the Earliest Reptiles.—With the possible exception of the Eosaurus, all the reptiles of the Carboniferous were Labyrinthodonts. They are so called on account of the extraordinary labyrinthine structure of their teeth, produced by the intricate infolding of the surface and of the cavity. The same structure is observed in ganoid teeth, but in a far less degree. The simple infoldings of Ganoids (Fig. 432, p. 343) become intricate in Labyrinthodonts (Fig. 572).

The Labyrinthodonts were probably the most complete example of a connecting type which has yet been discovered. First, they were true

FIG. 571.—Tuditanus radiatus, × ½ (after Cope).

FIG. 572.—Section of Tooth of a Labyrinthodont.

Amphibians in the strictest sense, having all of them in the early stages of their life—some throughout life—both lungs and gills, and thus connecting water-breathers with air-breathers. Again, they were very different from the slimy-skinned Amphibians of the present day, in being covered, at least partly, with bony scales over the body, and with closely-fitting bony plates over the head. Again, they differed wholly from the present Amphibians in having jaws thoroughly armed with very large and powerful teeth, the structure of which is labyrinthine. All of these characters connected them with Sauroid fishes which preceded them, and the great Saurian reptiles which succeeded them. Finally, they seemed to possess also characters connecting them with several orders of subsequently-existing reptiles. In the Labyrinthodonts and Sauroid fishes we can almost find the point of separation of the two great branches, Reptile and Fish, of the vertebrate stem; and in the

former the commencing differentiation of the several orders of Reptiles. All the earliest amphibians had persistent notochord (Cope).

Some General Observations on the Whole Palæozoic.

We have defined geology as the history of the evolution of the earth. *Evolution*, therefore, is the central idea of geology. It is this idea alone which makes geology a distinct science. This is the cohesive principle which unites and gives significance to all the scattered facts of geology; which cements what would otherwise be a mere incoherent pile of rubbish into a solid and symmetrical edifice. It seems appropriate, therefore, that at the end of the long and eventful Palæozoic era we should glance backward and briefly recapitulate the evidences of progressive change (evolution), physical, chemical, and vital.

Physical Changes.—The Palæozoic era opened on this continent with a V-shaped mass of land—the Laurentian area—to the north; also, a land mass of Laurentian rocks, of unknown shape and extent, on the eastern border, and probably some islands and masses of larger extent in the Rocky Mountain region. This condition of things is represented on the map on page 290. Throughout the Palæozoic era there was an accretion of land to this nucleus by upheaval of contiguous sea-bottoms; a development of the continent *southward* (and perhaps northward) from the northern area, and both eastward and westward from the eastern border area, until at the end of the Palæozoic the eastern half of the continent included *certainly* all the Laurentian, Silurian, Devonian, and Carboniferous areas shown on the map on page 289, and probably also some on the eastern and western border of this area, which was subsequently covered by the sea, and is therefore now concealed by more recent deposits. The loss of Palæozoic land on the eastern border probably took place during the *Appalachian revolution*. In the Rocky Mountain region the development was probably less steady. Unconformity of Carboniferous on Silurian strata shows extensive land-areas there during Devonian times. Thus it is seen that the continent was already sketched in the beginning of the Palæozoic, and the process of development went on during that era, so that at the end the outlines of the continent were already unmistakable. We shall trace the further development hereafter.

Chemical Changes.—Progressive changes in chemical conditions are no less evident. At first, i. e., before the Archæan era—before the existence of life on the earth—the atmosphere, as shown by Hunt ("Essays," p. 40, *et seq.*), was loaded with carbonic acid, representing all the *carbon and carbonates* in the world; with sulphuric acid representing all the *sulphur and sulphates;* with hydrochloric acid representing all the *chlorides;* and with aqueous vapor representing all the *water* in the world. Of course, such a condition rendered life impossible. From this primeval atmosphere, by cooling, the strong acids were first pre-

cipitated with the water; and afterward more slowly the carbonic acid, by the action of this acid upon the primeval silicates, with the formation of carbonates, especially limestone. All limestones, therefore, represent so much carbonic acid withdrawn from the air. This withdrawal proceeded through the whole Archæan, Silurian, and Devonian. During the Carboniferous, the purification of the air was accelerated by the growth of vegetable matter and its preservation as coal, as already explained, page 356. In this method of withdrawal the oxygen of the carbonic acid is returned, and the air becomes more oxygenated.

Progressive Change in Organisms. — Corresponding with these changes, physical and chemical, it is natural to expect changes in species, genera, families, etc., of organisms: and such we find. The law of *continuance* or *geological range* of species, genera, families, orders, is very similar to that of *extent* or *geographical range* of the same groups (p. 157); i. e., the laws of distribution in *time* are similar to those of distribution in *space*. The *period of continuance* (range in time) of species is, of course, less than that of genera, and that of genera less than that of families, etc. According to Prof. Hall, there have been in the Silurian and Devonian ages alone at least *thirty almost complete changes of species*. The changes of genera are, of course, much less numerous, and those of families still less than those of genera. These general laws may be illustrated by any Palæozoic order; but I select the order of Trilobites, because they are very numerous, very diversified, and well studied, and because they *came in* with the Palæozoic, *continued* throughout the whole era, and then passed away forever.

The following diagram illustrates these laws in the order of Trilobites. It is seen that this order continues through the whole era, commencing in small numbers, reaching its highest development in the Lower Silurian, and declining to the end. But the *families* are changed several times. Six groups are given, to show how they come and go successively. If we should attempt the distribution of *genera*, the changes would be much more numerous, and of *species* still more so. In the lower portion of the diagram we have attempted to show in a very general way how the distribution of species of Calymene and Acidaspis might be represented.

General Comparison of the Fauna of Palæozoic with that of Neozoic Times.—The greatest change which has ever occurred in the history of the organic kingdom took place at the end of the Palæozoic era. As human history is primarily divided into Ancient and Modern, so the whole history of the earth may be properly divided into *Palæozoic* and *Neozoic* times. We wish to contrast broadly the faunæ of these two great divisions of time. In the diagram (p. 411), the vertical line represents the dividing line between the *old* and the *new* time-world.

In this country it is appropriately called the Appalachian revolution. On the left is the Palæozoic, on the right the Neozoic. When families or orders of animals are placed on one or the other side without mark, it means that they are the *only kind* of the contrasted families found on that side, or nearly so. If the orders or families so placed are

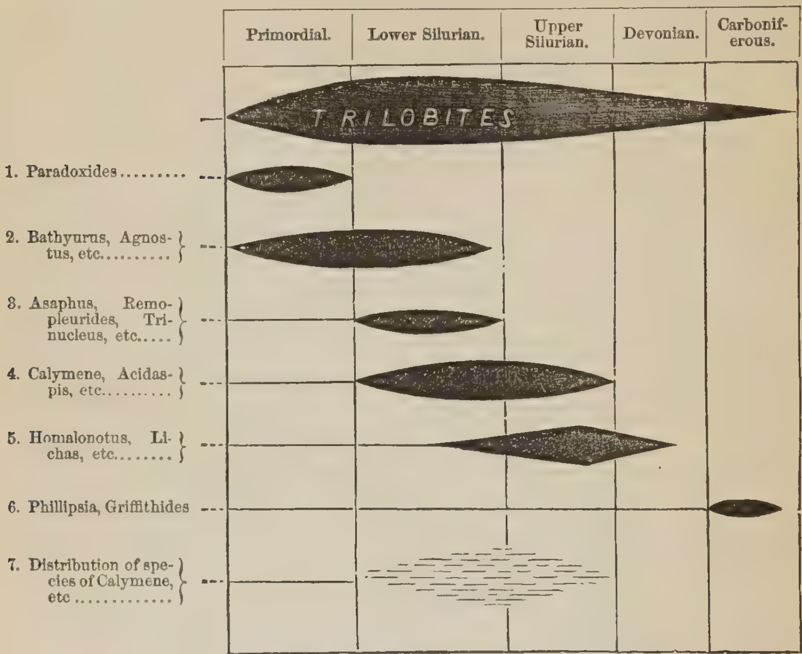


FIG. 573.—Diagram illustrating Distribution of Families, etc., in Time.

marked with the sign +, it means that they are the *predominant kinds.* For example, among Cephalopods, the Tetrabranchs, or shelled family, are the *only* kinds found in the Palæozoic; in the Neozoic, both families exist, but the Dibranchs or naked ones vastly *predominate.*

General Picture of Palæozoic Times.

Perhaps it is not inappropriate to group some of the more important facts in a very brief outline-picture of Palæozoic times. We must imagine, then, *wide* seas and *low* continents of *small extent;* a hot, moist, still air, loaded with carbonic acid, stifling and unsuited for the life of warm-blooded animals. If an observer had walked along those early beaches he would have found cast up, in great numbers, the shells of Brachiopods; clinging to the rocks and hiding away among their hollows, instead of sea-urchins and star-fishes and crabs, he would have found

Palæozoic times........................ | ..Neozoic times.

RADIATA.

Corals.

Quadripartita........................ | ..Sexpartita.

Echinoderms.

+ + Stemmed, or Crinoids........... | ..Free, or Echinoids and Asteriods + +.

Crinoids.

+ Armless, or simple arms............ | ..Plumose arms.

MOLLUSKS.

Bivalves.

+ Brachiopods .... | ..Lamellibranchs + +.

Brachiopods.

+ Square-shouldered.................. | ..Sloping-shouldered.

Lamellibranchs.

+ Unsiphonated...................... | ..Siphonated +.

Gasteropods.

Marine .... | ..Land, fresh-water, and marine.

Marine.

Unbeaked—Herbivorous.............. | ..Beaked—Carnivorous +.

Cephalopods.

Shelled, or Tetrabranchs.............. | ..Naked, or Dibranchs + +.

Shelled.

+ Straight........................... | ..Coiled.

Orthoceratites.

Goniatites.

Ceratites.

Ammonites.

N — a — u — t — i — l — u — s.

ARTICULATA.

Crustacea.

Entomostraca........................... | ..Malacostraca +.

Trilobites.

Limuloids.

Macrourans.

Brachyourans.

VERTEBRATA.

Fishes.

Heterocercals......................... | ..Homocercals +.

Ganoids and Placoids.... | ....Teleosts +.

Placoids.

Cestracionts.

Hybodonts.

Squalodonts.

Reptiles.

Amphibians .... | ..True Reptiles.

crinoids and trilobites. In the open sea he would have found as rulers, instead of whales and sharks and teleosts and cuttlefish, huge cuirassed

Sauroids and the straight-chambered Orthoceras. Turning to the land, he would have seen at first only desolation; for there were no land-plants until the Devonian, and almost no land-animals until the Coal. During the Coal there were extensive marshes, overgrown with great trees of Sigillaria, Lepidodendron, and Calamites, with dense underbrush of Ferns, inhabited by insects and amphibians; no umbrageous trees, no fragrant flowers or luscious fruits, no birds, no mammals. These "dim, watery woodlands" are flowerless, fruitless, songless, voiceless, except the occasional chirp of the grasshopper. If the observer were a naturalist, he would notice, also, the complete absence of modern types of plants and animals—it would be like another world.

This long dynasty was overthrown, this reign of Fishes ended, the physical conditions described above changed, and the whole fauna and flora destroyed or transmuted, by the Appalachian revolution. At the end of the Palæozoic, the sediments which had been so long accumulating in the Appalachian region at last yielded to the slowly-increasing horizontal pressure, and were mashed and folded and thickened up into the Appalachian chain, and the rocks metamorphosed. In America, this chain is the monument of the greatest revolution which has taken place in the earth's history.[1] Similar and very extensive changes in physical geography must have taken place in other portions of the globe, otherwise we cannot account for the enormous changes in physical conditions and fauna and flora. Many of these have been traced, but we cannot yet trace them as clearly as in America.

Transition from the Palæozoic to the Mesozoic—Permian Period.

The Permian a Transition Period.—The Palæozoic era was closed and the Mesozoic inaugurated by the Appalachian revolution. All the great revolutions in the earth's history are periods of oscillations. Such oscillations produce unconformity. They also produce changes of climate, and therefore of fauna and flora. We find, therefore, that the Mesozoic rocks are universally, or nearly universally, unconformable on the Carboniferous; and, corresponding with this unconformity, there is a wonderful change in fauna and flora—a change the greatness of which we have attempted to show in the contrast on the preceding page. Now, the older geologists regarded this change as one of instantaneous destruction and recreation, because they took no account of a lost interval. But we have already shown (pp. 179, 291) that in all cases of unconformity there *is* such a lost interval, which in some cases is very large. In order to account for the very great change in the organic world, it is only necessary to suppose that periods represented by unconformity are *critical* periods in the earth's history—periods of rapid change in physical geography, climate, and therefore of rapid change in fauna and flora, by the passing out of old types and the differentiation of new

[1] See Appendix.

types. Unfortunately, in the earth's history, as in human history, it is exactly these critical periods—these periods of change and revolution—the record of which is apt to be lost. In both histories, too, this is truer the farther back we go. Of the long interval between the Archæan and Palæozoic, not a leaf of record has been yet recovered ; but of the interval now under discussion many leaves of record have been recovered. These have been bound together in a separate volume or chapter and called the *Permian.* I shall regard the Permian, therefore, as essentially a *transition period ;* its rocks were deposited during the period of commotion; its fossil types are in a state of change, though more nearly allied to the Palæozoic.

From what has just been said, it will be anticipated that the unconformity of the Mesozoic on the Palæozoic sometimes takes place between the lowest Mesozoic and the Permian, and sometimes between the Permian and the Coal. The Permian, therefore, is sometimes conformable with the Coal, as, e. g., in this country ; sometimes conformable with the Triassic, as in England. It thus allies itself stratigraphically sometimes with the Palæozoic, sometimes with the Mesozoic. Paleontologically it is always more allied to the Palæozoic. The English section, and the history of opinion concerning it, admirably illustrate this point. Fig. 574 is an ideal section through the Devonian,

FIG. 574.

the Coal and Triassic (Lower Mesozoic) of England. Lying unconformably on the eroded surface of the Coal, *b*, there is seen a continuous and perfectly conformable series of strata, *a.* This series, moreover, is lithologically characterized throughout, especially the lower part, by frequent alternations of Red sandstones, and therefore has been called *New Red* sandstone, to distinguish it from the Devonian, which is often called Old Red sandstone. It is further distinguished throughout, especially the upper part, by variegated shales, and therefore called altogether *Poikilitic* group. It is also distinguished throughout by the presence of salt, and therefore called the *Saliferous* group. Here, then, there were the strongest reasons for regarding the whole as one group, distinctly separated by unconformity from the underlying Coal. The line of unconformity was, therefore, naturally believed to be the line between Palæozoic and Mesozoic. Unfortunately, the lower portion is very barren of fossils, and this means of correcting the stratigraphic conclusion was at first nearly wanting. When fossils

were discovered in sufficient numbers, however, they showed a greater alliance with the unconformable Coal below than with the conformable strata above. Thus, if we make the division between Palæozoic and Mesozoic on stratigraphical grounds, we would find it between the Coal and the overlying strata ; while, if we make it on paleontological grounds, we would have to draw the line through the midst of the conformable strata, *a*, giving one half to the Palæozoic and the other half to the Mesozoic. The lower Palæozoic half is called the *Permian.*

As a broad general fact, therefore, the great commotion which is called the Appalachian revolution took place, or commenced to take place, at the end of the Coal period. But the fauna and flora were not immediately exterminated, but struggled on, maintaining, as it were, a painful existence under changed conditions, themselves meanwhile changing, until complete and permanent harmony was reëstablished with the opening of the Mesozoic. If we may use an illustration, the Appalachian revolution was the death-sentence of Palæozoic types, but the sentence was not instantly executed. This transition period, between the sentence and the execution of Palæozoic types, is the Permian.

It is well here to draw attention to the fact of this great change of organisms, the greatest in the whole history of the earth, taking place

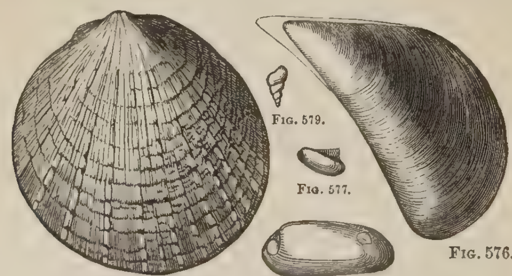


Fig. 579. Fig. 577. Fig. 576. Fig. 575. Fig. 578.

Figs. 575–579.—Permian Shells (after Meek): 575. Eumicrotis Hawnii. 576. Myalina Permiana. 577. Bakewellia parva. 578. Pleurophorus subcuneatus. 579. A Gasteropod.

in the midst of conformable strata (Fig. 574, *a*). Evidently the change must have been comparatively rapid.

We have given the history of change of opinion in regard to the English section (Fig. 574), because it is a tpye of many discussions and changes which have occurred and will still occur in geological opinion.

The Permian has been found in the United States, in Kansas, bordering on, and conformable with, the coal of that region (map, p. 289) ; also in New Mexico and Western Texas, and probably also overlying the coal of Illinois (Cope). Until recently nothing of interest has been found in the American Permian, except a few shells, but now a considerable number of fishes, amphibians, and reptiles are known.

Fig. 580.—Walchia piniformis (Permian of Europe).

Fig. 582.

Fig. 581. Fig. 583. Fig. 584.

Figs. 581-584.—Permian Brachiopods: 581. Producta horrida. 582. Lingula Credneri. 583. Terebratula elongata. 584. *a*, *b*, Camarophoria globulina (after Nicholson).

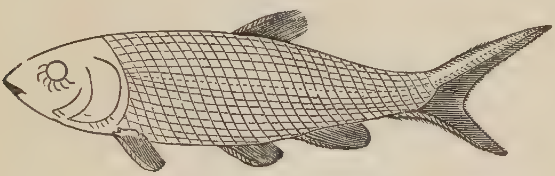


Fig. 585.—Restoration of Palæoniscus.

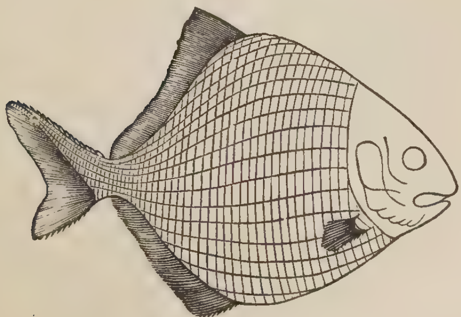


Fig. 586.—Platysomus gibbosus (Permian of Europe).

In Europe the flora consists principally of Ferns, Calamites, and Lepidodendrids, closely allied to those of the Coal, and several species of Walchia (Fig. 580), Voltzia, Ulmannia, genera of Conifers. In fact, Conifers are more abundant and varied than in the Coal.

In the fauna, Trilobites and Goniatites are gone, but a few Orthoceratites and a few square-shouldered Brachiopods, such as Productus (Fig. 581) and Spirifer, are still found, as also are several genera of Ganoids observed in the Coal (Fig. 585), and some characteristic of this period (Fig. 586).

Along with Labyrinthodonts, already found in the Coal, are also found now some Thecodont (*socket*-toothed) reptiles, allied to Crocodilians, which show a decided advance on the Coal reptiles. Unless we except the Eosaurus, these are the first *true reptiles* found. They are probably the progenitors of the crocodiles, though they have also affinities with the Dinosaurs (Huxley).[1]

CHAPTER IV.

MESOZOIC ERA—AGE OF REPTILES.

THE Palæozoic era, we have seen, was very long, and very diversified in dominant types, of both animals and plants. It was during this long era that originated nearly all the great branches, and even sub-branches, of the organic kingdom. We have during this era, therefore, three very distinct ages: an age of Invertebrates, an age of Fishes, and an age of Acrogens and Amphibians. The Mesozoic was far less long and far less diversified in dominant types. It consists of only one age, viz., the age of Reptiles. Never in the history of the earth, before or since, did this class reach so high a point in numbers, variety of form, size, or elevation in the scale of organization.

General Characteristics.—The general characteristics of the Mesozoic era are the *culmination of the class of Reptiles* among animals, and of Cycads among plants, and the *first appearance* of *Teleosts* (common osseous fishes), *Birds*, *Mammals* among animals, and of *Palms* and *Dicotyls* among trees.

Subdivisions.—The Mesozoic era is divided into three periods, viz.: 1. *Triassic*, because of its threefold development where first studied in Germany; 2. *Jurassic*, because of the splendid development of its strata in the Jura Mountains; 3. *Cretaceous*, because the chalk of England and France belongs to this period.

[1] See APPENDIX.

Mesozoic Era.	3. Cretaceous period. 2. Jurassic period. 1. Triassic period.

In this country the Triassic and Jurassic are not so distinctly separable as they are in Europe, nor as they are from the Cretaceous. They form, in fact, one series, and if the Mesozoic had been studied first in this country, the whole would probably have been divided into only two periods. We shall therefore speak of the Mesozoic of this country as consisting of two periods, viz., the *Jura-Trias* and the Cretaceous. On account of their fuller development in Europe, it will be best to speak, first, of the Triassic *generally*, then of the Jurassic generally, taking our illustrations mainly from European sources, and then of the Jura-Trias in America. Also, on account of the comparative poverty of the Trias in remains, we will dwell much less on this period than on the subsequent Jurassic; for in this latter period culminated all the distinctive characters of the Reptilian age.

Section 1.—Triassic Period.

As already stated, the Triassic strata are always unconformable with the Coal, and the period opens with a fauna and flora wholly and strikingly different from the preceding. In some places, however, there is found an intermediate series, the Permian, sometimes conformable with the Coal and unconformable with the Trias, sometimes conformable with the Trias and unconformable with the Coal. Its fauna and flora are also to some extent intermediate, though more nearly allied to those of the Coal. The explanation of this has already been given.

Subdivisions.—The subdivisions of the Triassic rocks and period in several countries are given below:

German.	French.	English.
3. Keuper.	Marne irisée.	Variegated marl.
2. Muschelkalk.	Muschelkalk.	Wanting.
1. Bunter Sandstein.	Grès bigarré.	Upper New Red sandstone.

The *flora* of the Trias is very imperfectly known. We find, however, no longer the great coal-making trees of the Carboniferous—Sigillarids, Lepidodendrids, and Calamites—though Tree-ferns still continue in abundance. The forest-trees seem to have been principally *Tree-ferns*, *Cycads*, and *Conifers*, although the last two did not reach their highest development until the next period. For this reason we will put off the fuller discussion of them until we come to that period.

FIG. 588.

FIG. 587. FIG. 589.

FIGS. 587–589.—TRIASSIC CONIFERS AND CYCADS (after Nicholson): 587. Voltzia heterophylla. 588. Pterophyllum Jægeri. 589. Podozamites Emmonsi.

Animals.—Among Echinoderms we find no longer any Cystids and Blastids; but *Crinids*, beautiful *lily Encrinites*, with long plumose arms, are very abundant (Fig. 590). Among *Brachiopods* the familiar square-shouldered forms, including the *Spirifer* family, the *Strophomena* family, and the *Productus* family, are almost if not wholly gone; only a few Spirifers remain. Among *Cephalopods*, we find no longer *Orthoceratites* or *Goniatites*, but *Ceratites* (Fig. 598) take their place, and *Ammonites* begin. In Ceratites, the suture is more complex than in Goniatites, but not so complex as the subsequent Ammonite. Among

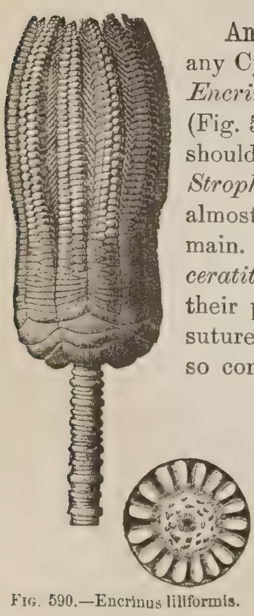
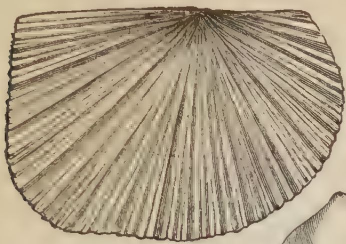


FIG. 590.—Encrinus liliformis.

FIG. 591.—Aspidura loricata

Crustaceans, we find no longer *Trilobites* nor huge *Eurypterids*, but *Macrourans*, which began in the Carboniferous, are now more abundant, and of more modern forms (Fig. 599).

Fishes.—Among fishes, still we find *no Teleosts*, only Ganoids and



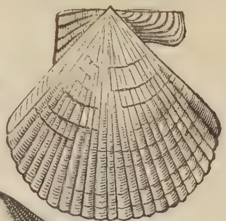


Fig. 593.

Fig. 592.

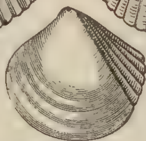


Fig. 595.

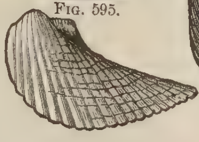


Fig. 594. Fig. 596. Fig. 597.

Figs. 592–597.—Lamellibranchs (after Nicholson): 592. Daonella Lommellii. 593. Pecten Valoniensis. 594. Myophoria lineata. 595. Cardium Rhæticum. 596. Avicula contorta. 597. Avicula socialis.

Placoids; but while the Ganoids are some of them heteroceral or vertebrated-tailed like the Palæozoic Ganoids, some are only *slightly* ver-

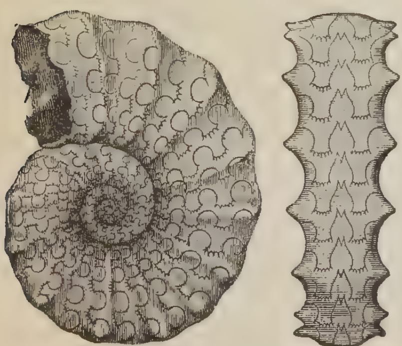


Fig. 598.—Ceratites nodosus.

Fig. 599.—Pemphyx Sueurii.

tebrated, and some wholly non-vertebrated-tailed, or homoceral. The *Ceratodus*, a remarkable genus of fishes, one species of which still lives in Australian rivers (Fig. 424, p. 341), is traced back to this period. Being

FIG. 600.

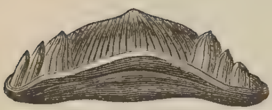


FIG. 601.

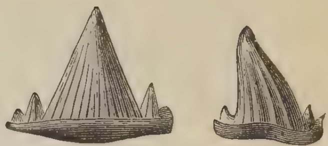


FIG. 602.

FIGS. 600–602.—TRIASSIC FISHES: 600. *a*, Dental Plate of Ceratodus serratus; *b*, Dental Plate of Ceratodus altus, Keuper (after Agassiz). 601. Acrodus minimus. 602. Hybodus apicalis (after Agassiz).

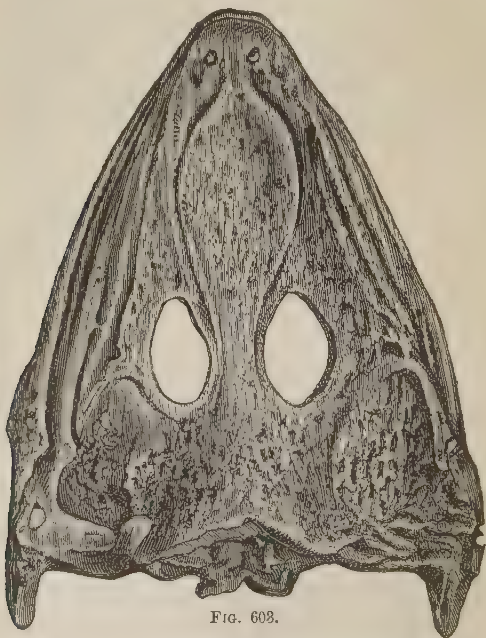


FIG. 603.

FIG. 604.

FIGS. 603, 604.—TRIASSIC REPTILES—*Labyrinthodonts*: 603. Mastodonsaurus Jægeri. 604. Trematosaurus (after Huxley).

known in a fossil state only by the curious palatal teeth (Fig. 600), it has heretofore been classed with Placoids. The Placoids are partly *Cestracionts* (Fig. 601), and partly *Hybodonts* (Fig. 602).

Reptiles.—This class was represented by Labyrinthodonts, Enaliosaurs (marine Saurians), Rhynchosaurs (beaked Saurians), and Lacertians (lizards).

Marine Saurians reached their culmination in the next period, and we will therefore put off discussion of them until then. *Labyrinthodonts* have already been described in connection with the Carboniferous, where they first occur. They *culminated*, however, in the Triassic, and then became extinct. They reached in the Triassic gigantic proportions. The head of the Labyrinthodon (Mastodonsaurus) Jægeri (Fig. 603) was more than three feet long and two feet wide, and one of the teeth was three and one-half inches beyond the jaw, and one and a half inch in diameter at base (Owen, Figs. 605, 606). *Tracks* made by Labyrinthodonts have been found in England and in Germany, in rocks

Fig. 605.

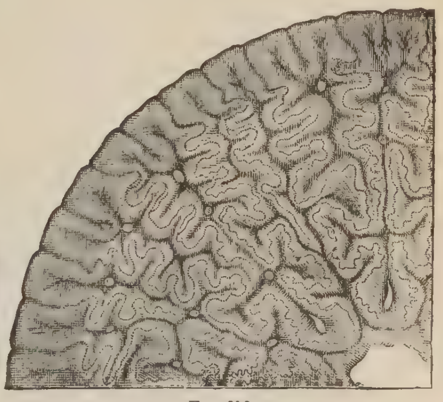


Fig. 606.

Figs. 605, 606.—Triassic Reptiles—*Labyrinthodonts:* 605. Tooth of Labyrinthodon, natural size. 606. Section of same enlarged, showing structure.

of this period. The unknown animal was at first called Cheirotherium (hand-beast), because of the resemblance of the track to the impression of a very fat human hand (Fig. 607). Both the tracks and the skeleton show that the hind limbs were much longer than the fore. In the

tracks figured below, the hind-tracks are eight inches and the fore-tracks about four inches long. Others have been found of much greater size.

The *beaked Saurians*, also called *Anomodonts* (lawless-toothed),

FIG. 607—Tracks of a Cheirotherium—a Labyrinthodont.

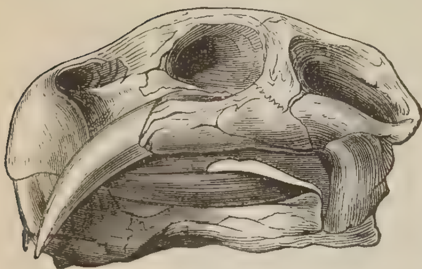


FIG. 608.

FIG. 609.

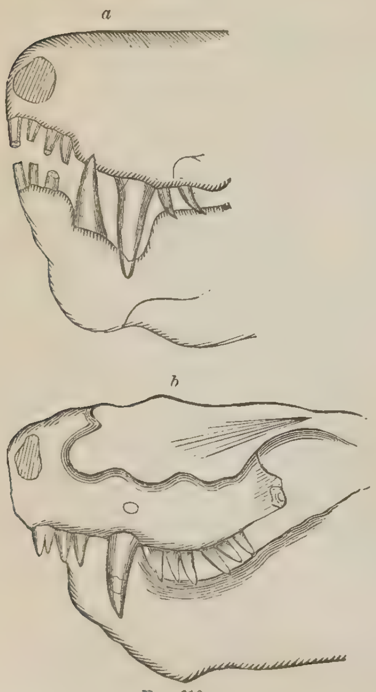


FIG. 610.

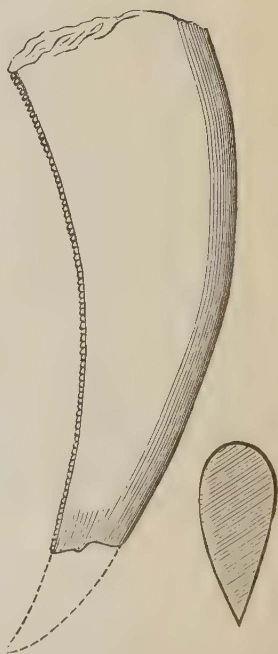


FIG. 611.

FIGS. 608-611.—TRIASSIC REPTILES (after Owen)—*Anomodonts and Theriodonts;* 608. Dicynodon lacerticeps. 609. Oudenodon Bainii. 610. *a b*, Lycosaurus. 611. Canine Tooth of Cynodracon, natural size.

are peculiar to this period. The most extraordinary of this remarkable group is the Dicynodon (two-canine-toothed). This was a saurian with the head and nipping, horny beak of a tortoise, and with two long curved overhanging canine teeth from the upper jaw (Fig. 608). Several species have been found, in one of which (the tigriceps) the head was twenty inches long and eighteen inches wide. They have been found only in the fresh-water Triassic of South Africa (Karoo beds). Several other genera of the same order (Anomodonts) have been found in the same locality. The Oudenodon had a nipping, horny beak (Fig. 609), without teeth of any kind.

According to Prof. Owen, this remarkable order combined the characters of crocodiles, tortoises, and lizards.

Very recently from the same South African strata (Karoo beds) Prof. Owen has described a great number of remarkable reptiles, including Lycosaurus, Cynodracon, Tigrisuchus, Cynosuchus, and many others, which, from some mammalian characters, especially in the teeth, he calls Theriodonts (beast-tooth). The strata in which they have been found are usually assigned to the Triassic, but they may be Permian, as similar reptiles have been found in the Permian of the Ural. Figs. 610 and 611, taken from Owen, show the characters of these reptiles. From the same beds he also describes a remarkable reptile, which, on

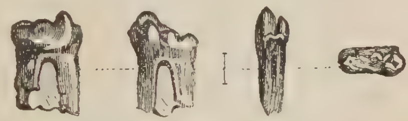


FIG. 612.—Tooth of the Microlestes antiquus.

FIG. 613.—Myrmecobius fasciatus, Banded Ant-eater of Australia.

account of certain characters connecting with Monotremes, especially the duck-billed Platypus, he calls Platypodosaurus.[1] If the Karoo beds be Permian, then this reptile was probably contemporaneous with the theromorphous reptiles described by Cope.

[1] *Quarterly Journal of Geological Society*, vol xxxvi., p. 414, 1880.

Birds.—No Birds have yet been found in the strata of the Triassic age, unless we except the so-called *bird-tracks* of the Connecticut Valley sandstone, which we will discuss further on.[1]

Mammals.—Remains of two or three *small insectivorous Marsupials* have been found in the uppermost Triassic, both of Europe and of the United States. Figures of a tooth of one of these, *Microlestes antiquus*, are given (Fig. 612), and also a figure of what is regarded as its nearest living congener (Fig. 613). But as these are found in very small numbers in the uppermost Triassic beds, and as similar animals are found in much greater numbers in the Jurassic, it seems best to regard these as anticipations, and to put off the discussion of the affinities of the earliest mammals until we take up that period.

Mammals probably preceded Birds. This is not a little remarkable. But it must be remembered that Birds are very closely allied to Reptiles, and may be regarded as a secondary offshoot of the reptilian branch.

Origin of Rock-Salt.

Neither rock-salt nor *coal* is confined to the rocks of any particular age. Both have been formed in every age; both are forming *now*. But as the subject of the origin of coal-deposits was discussed in connection with that age during which it was accumulated in the greatest abundance—the Carboniferous—so the origin of rock-salt is best discussed in connection with the so-called Saliferous or Triassic.

Age of Rock-Salt.—As already stated, rock-salt is found in strata of all ages, and is forming now. Moreover, there is none which deserves the name Saliferous to the same extent that the Carboniferous deserves its name. The salt of Syracuse, New York, is found in the Upper Silurian; that of Canada, which exists in immense beds 100 feet thick, is found in the Upper Silurian or Lower Devonian; that of Pennsylvania is Upper Devonian; of Southwest Virginia is sub-Carboniferous; of Petite Anse, Louisiana, is uppermost Cretaceous or lowest Tertiary (Hilgard). In Europe, the English salt-beds are Triassic, the German beds Triassic and Jurassic; the celebrated Polish beds at Cracow are Tertiary.

Mode of Occurrence.—Salt occurs in immense *beds* of pure rock-salt, or else impregnating strata. It is obtained by direct mining, or else by boiling down the saline waters either of natural springs or of artesian wells sunk into the salt-bearing strata. The further explanation of its mode of occurrence is best and most concisely given by comparing it with *coal.*

1. Like coal, it occurs in isolated *basins*, but these are far more limited than the great coal-fields. 2. Like coal, it is interstratified with

[1] Bird-like tracks have also been found in the Triassic of New South Wales.—*Quarterly Journal of Geological Society*, vol. xxxv., 511, 1879.

sands and clays, the whole series repeated often many times. In Galicia, for example, there are found seven salt-beds in the same section. 3. But it differs from coal, in the great *thickness* of the beds. In Canada the salt-bed is 100 feet thick (Gibson).[1] In Cheshire, England, there are two beds, one 100 feet, the other 90 feet thick, separated by thirty feet of shale. At Stassfurt a salt-bed has been penetrated 1,000 feet, and the bottom not yet reached.[2] 4. Recollecting the somewhat limited extent of basins, it is evident that salt-beds *thin out* far more rapidly than coal. The English salt-beds thin out fifteen feet per mile. Coal, therefore, lies in *extensive sheets*, salt in *lenticular masses*. 5. Coal has its characteristic valuable accompaniment in *iron-beds*, salt in beds of *gypsum*. Thus, as coal-measures consist of repetitions of sands, clays, occasional limestones, with valuable beds of coal and iron-ore many times repeated, so salt-measures consist of sands, clays, and occasional limestones, with valuable beds of salt and gypsum many times repeated. Gypsum-beds are often entirely separate from salt-beds, but each salt-bed is apt to be underlaid by gypsum. 6. While coal-measures are remarkable for the abundance of organic remains, both vegetable and animal, salt-measures are equally remarkable for extreme poverty in this respect. The presence of these remains in the one case, and their absence in the other, are the cause of the difference in the *color of the sandstones*. Coal-measure sandstones are *white* or *gray*, being leached of their oxide of iron by organic matter. Salt-measure sandstones are usually *red*, the iron being diffused as coloring-matter.

Theory of Accumulation.—We have already seen (p. 73) that salt-lakes are evaporated residues of river-water or sea-water in dry climates, and are now, most of them, depositing salt: also, that sea-water evaporated deposits first gypsum, then salt: also, that these deposits of salts and gypsum alternate annually with sediments of sand and clay—the salt or gypsum deposit representing the dry season, and the mechanical deposits representing the season of floods. It is, therefore, natural to look in this direction for an explanation of salt and gypsum deposits — to think that salt-basins are dried-up salt-lakes. But the immense thickness of the beds plainly shows that there must have been important modifications of this process. It is plain that the alternations of salt and sedimentary deposit were not *annual* but *secular*.

The conditions under which salt-measures were formed were probably as follows: Imagine a low, flat coast, with salt lagoons or lakes, connected periodically with the sea, by changing direction of winds, or

[1] *American Journal of Science*, vol. v., p. 362, 1873.

[2] Bischof, "Chemical Geology," vol. i., p. 383. "The Berlin salt-well is 4,172 feet deep, and, except the upper 292 feet, penetrates solid salt" (*Nature*, vol. xv., p. 240, 1877).

at longer intervals by oscillations of the earth-crust; and subjected to hot sun and *dry climate*, and without contiguous mountains furnishing abundant sediment. Under these conditions either gypsum alone, or gypsum first and then salt, might accumulate by deposit indefinitely. If the water of the lagoon was kept, by periodic fresh supply of sea-water, just below the saturating point for salt, *gypsum only* would continue to deposit; but if the concentration should reach the point of saturation for salt, then salt would deposit indefinitely, since fresh supplies would come in from the sea.

In the deposits of salt-lakes or saturated lagoons we would not expect to find many animal remains, but the tracks of animals along their muddy shores, as also sun-cracks and rain-prints, would be found as on other shores. Now, although in the strata associated with salt organic remains are rare, shore-marks of all kinds are common.

Section 2.—Jurassic Period.

This is the culminating period of the Mesozoic era and Reptilian age. In it all the characteristics of this age reach their highest development. We must discuss this somewhat more fully than the last.

The strata belonging to this period are magnificently developed in the Jura Mountains, and hence the name Jurassic. These mountains are an admirable illustration of the manner in which ridges and valleys

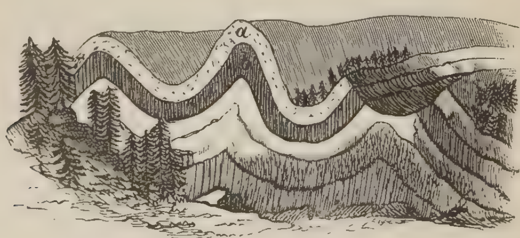


Fig. 614.—Section of the Jura Mountains.

are formed by the folding of strata (Fig. 614); they also abound in fossils of this period.

English geologists call the period *Oölite* (egg-stone), on account of the abundant occurrence in that country of a peculiar limestone composed often wholly of small rounded grains like the roe of a fish. They divide the whole period into three epochs, viz.: 1. *Lias;* 2. *Oölite proper;* 3. *Wealden.* They also subdivide the Oölite proper into *Lower*, *Middle*, and *Upper* Oölite, separated by intervening Oxford and Kimmeridge clays. All these divisions and subdivisions are well shown in the following section passing from London westward. This

section is interesting not only as exhibiting all the divisions and subdivisions of the Oölitic period, but also as showing their conformity

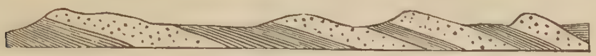


Fig. 615.

among themselves and with the overlying chalk, and the unconformity of these with the overlying Tertiary. It also shows how parallel ridges and intervening hollows are formed by the outcropping of a series of strata alternately hard and soft.

Origin of Oolitic Limestones.—Oölitic limestones are *now* forming on coral shores by cementation of rolled and rounded coral-sand grains (p. 148.) But oölitic grains often contain small foreign particles around which the limestone is arranged concentrically. In such cases the rounded grains "seem to have been gathered by attraction, out of the calcareous mud, round nuclei of previously-solidified matter" (Phillips).

Jurassic Coal-Measures.—In the Jurassic times we have reproduced on a large scale the conditions favorable for luxuriant growth of plants, and for their accumulation and preservation in the form of *coal*. Hence in many countries we have Jurassic coal-fields. To this period belong the Yorkshire coal of England and the Brora coal of Scotland. To this or the previous period belong the coal-fields of North Carolina and Eastern Virginia, and some of the coal-fields of India[1] and China. The fine coal-measures of New South Wales, Australia, covering an area of 20,000 square miles, have been usually referred to this period, but they are probably Permian or Carboniferous. Jurassic coal-measures have a general structure similar to those of the Carboniferous. Like the latter, they consist of alternations of sands and clays, and occasional limestones, containing seams of coal and beds of iron-ore. The iron-ore too is of the same kind, viz., *clay iron-stone*. We find here also underclays, with stumps and roots, and roof-shales filled with leaf-impressions. It is fair to conclude, therefore, that the mode of accumulation was similar to that already described, viz., in marshes subject to occasional floods. Jurassic coal, though perhaps inferior as a general rule to Carboniferous, is often of good quality, occurring in thick and profitable seams.

Dirt-Beds—Fossil Forest-Grounds.—Coal-seams with their underlying clays are fossil *swamp-grounds;* dirt-beds are fossil *soils* or *forest-grounds*. The one graduates insensibly into the other, and both are occasionally found in all strata, from the Devonian upward. In the

[1] The plant beds of India (Gondwana series of Indian geologists) are Permian to Jurassic inclusive.—*Manual of Indian Geology*, p. 102, *et seq.*

Upper Oölite of England, at the Isle of Portland and elsewhere, there occurs an interesting example of such a fossil forest-ground with the erect stumps and ramifying roots still *in situ*, though silicified, and the logs, also silicified, still lying on the fossil soil (Figs. 616, 617). It is evident that the sequence of events at this place in Jurassic times was as follows: 1. The place was sea-bottom, and received sediment which consolidated into Portland-stone. 2. After being flooded and covered with river-deposit, it was raised to land and became forest-ground, covered with trees and other vegetation peculiar to that time, the decaying

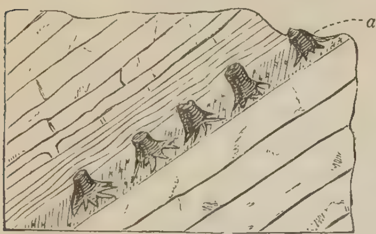


Fig. 616.—Section in Cliff east of Lulworth Cove: *a*, Dirt-bed.

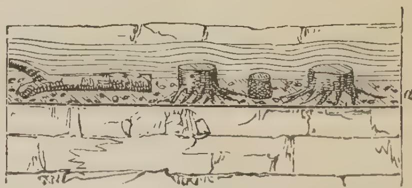


Fig. 617.—Section in the Isle of Portland: *a*, Dirt-bed.

leaves of which accumulated as a rich and thick vegetable mould. 3. It became flooded with fresh water, and the trees therefore died and rotted to stumps. 4. The whole ground, with its stumps and logs, became covered with mud, which hardened into slates. 5. Finally, the whole was raised into high land, and in the first figure (Fig. 616) tilted at considerable angle.

Thus, we have here not only an old forest-ground with its vegetable mould, but also the stumps and logs of the trees which grew there, still in place; and closer examination easily detects the kinds of trees which grew in the forest. They are *Cycads* and *Conifers* (Figs. 618–625).

Fig. 618.—Zamia spiralis, a living Cycad of Australia.

Still further, there is good reason to believe that the remains of some of the animals which roamed these forests have been found. Of these we will speak in their proper place.

Plants.

Although the conditions under which coal was accumulated were probably similar in all geological periods, yet the kinds of plants out

FIG. 619.—Cycas circinalis, × $\frac{1}{120}$, a living Cycad of the Moluccas (after Decaisne).

of which the coal was made varied. As already seen, the principal coal-plants of the Carboniferous period were vascular Cryptogams. On the contrary, the principal coal-plants of the Jurassic period were *Ferns*,

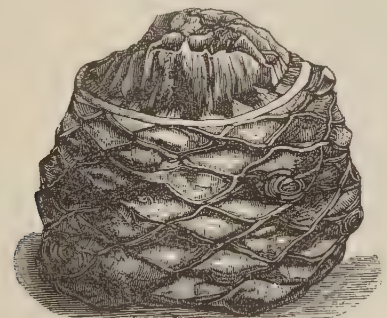


FIG. 620.—Stem of Cycadeoidea megalophylla.

Cycads, and *Conifers*. The Jurassic may be called the *age of Gymnosperms*, as the Carboniferous was the age of Acrogens. The Gym-

nosperms, especially the family of Cycads, reached here their highest development. This is shown in Fig. 245 on page 281. The leaves (Fig. 621) and short stems of Cycas and Zamia (Fig. 620) are found very

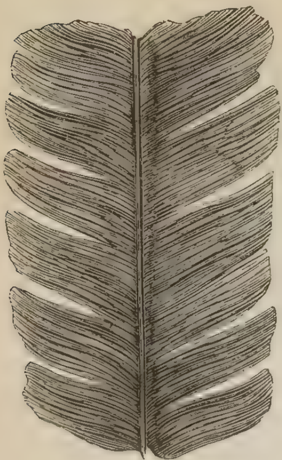


Fig. 621.

Fig. 622.

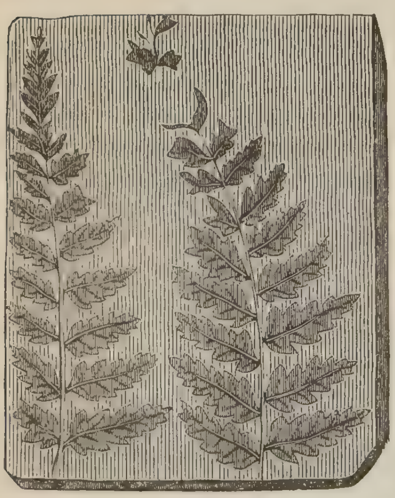


Fig. 623.

Fig. 624.

Figs. 621–624.—Jurassic Plants—*Cycads and Ferns:* 621. Pterophyllum comptum (a Cycad). 622. Hemitelites Brownii (a Fern). 623. Coniopteris Murrayana. 624. Pachypteris lanceolata.

abundantly in connection with the coal-bearing strata. It is probable, therefore, that the coal is composed largely of these plants. Some

remains of Jurassic plants are given (Figs. 620–626), and also of living Cycads (Figs. 618, 619), for comparison.

FIG. 625.

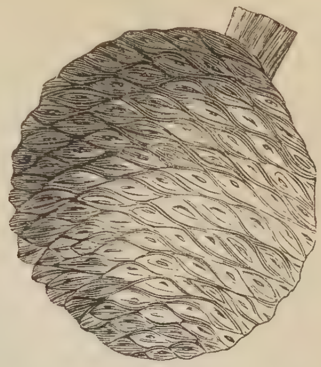


FIG. 626.

FIGS. 625, 626.—JURASSIC PLANTS—*Conifers:* 625. Cone of a Pine. 626. Cone of an Araucaria.

Animals.

The animals of the Jurassic, both marine, fresh-water, and land, were very abundant, and have been well preserved. It is impossible, therefore, in the lower departments, to do more than touch lightly the most salient points. In the higher departments we will dwell a little longer.

Corals have assumed now the modern type and style of partitions (Fig. 627). Among Echinoderms, the *Crinids*, or plumose-armed Crinoids, are very abundant and very beautiful; in fact, they seem to have reached their highest point in abundance, diversity, and gracefulness of form (Figs. 628, 629). But the free forms, Echinoids and Asteroids, are now equally abundant (Figs. 630–632).

Brachiopods are still abundant, though far less so than formerly; but they now belong almost wholly to the modern or sloping-shouldered types, such as Terebratula and Rhynchonella. Only a very few small specimens of the Palæozoic type linger until the Lias.

Lamellibranchs, or common bivalves, are extremely abundant. Among the common and characteristic forms are Trigonia, Gryphæa, and Exogyra, belonging to the oyster family; and the strangely-shaped Diceras. It is interesting, also, to observe here the first appearance of the genus *Ostrea* (oyster).

Cephalopods.—One of the most striking characteristics of the Jurassic period is the culmination of the class of Cephalopods in *number, diversity* of forms, and, if we except some of the Silurian Orthoceratites, in *size.* They were represented by the Ammonites and the Belemnites, the one belonging to the order of Tetrabranchs, or shelled,

the other to the Dibranchs, or naked Cephalopods. It is important to observe that the highest order of Cephalopods, the Dibranchs, by far

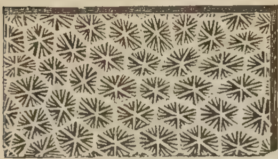


Fig. 627.

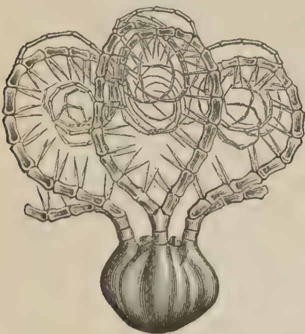


Fig. 629.

Fig. 632.

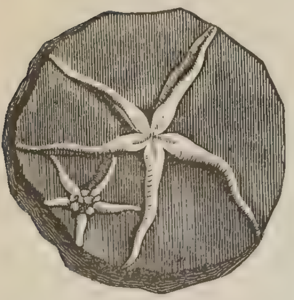


Fig. 630.

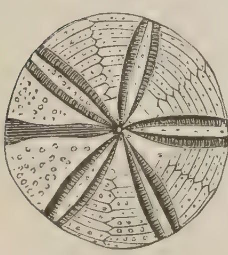


Fig. 631.

Fig. 628.

Figs. 627-632.—Jurassic Corals and Echinoderms: 627. Prionastrea oblongata. 628. Apiocrinus Roissianus. 629. Saccocoma pectinata (a free Crinoid). 630. Asteria lombricalis. 631. Clypeus Plotii. 632. *a b*, Hemicidaris crenularis.

the most abundantly represented at the present time, were introduced *here* for the first time.

Fig. 633.

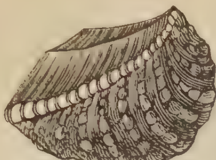


Fig. 634.

Fig. 635.

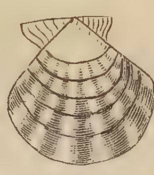


Fig. 636.

Fig. 637.

Fig. 638.

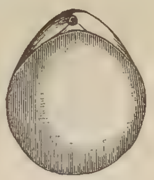


Fig. 639.

Fig. 640.

Figs. 633–640.—Jurassic Lamellibranchs and Brachiopods of England: 633. Astarte excavata. 634. Trigonia clavellata. 635. Ostrea Sowerbyi. 636. Pecten fibrosus. 637. Ostrea Marshii. 638. Rhynchonella varians. 639. Terebratula sphæroidalis. 640. Terebratula digona (after Nicholson).

Ammonites.—The Ammonite family, which is distinguished, as already explained (pp. 317, 332), by the dorsal position of the siphuncle and the complexity of the suture, is represented in extreme abundance by the

Fig. 641.—Ammonites Humphreysianus.

type-genus *Ammonites*. About 500 species of this genus are known, ranging in time from the Triassic through the Cretaceous. They are therefore characteristic of the Mesozoic. They varied extremely in

shape, and in size from half an inch to a yard or more in diameter. Below, and on page 433, we give figures of some of the most common species.

In the genus Ammonites the distinguishing character of the family, viz., the complexity of the suture, reached its highest point. In this

Fig. 642.

Fig. 643.

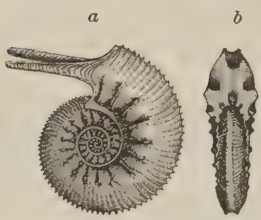


Fig. 644.

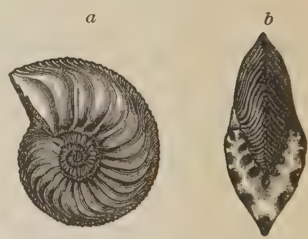


Fig. 645.

Figs. 642–645.—Jurassic Cephalopods—*Ammonites:* 642. Ammonites bifrons. 643. Ammonites margaritanus. 644. Ammonites Jason: *a*, side-view; *b*, showing suture. 645. Ammonites cordatus: *a*, side-view; *b*, showing suture.

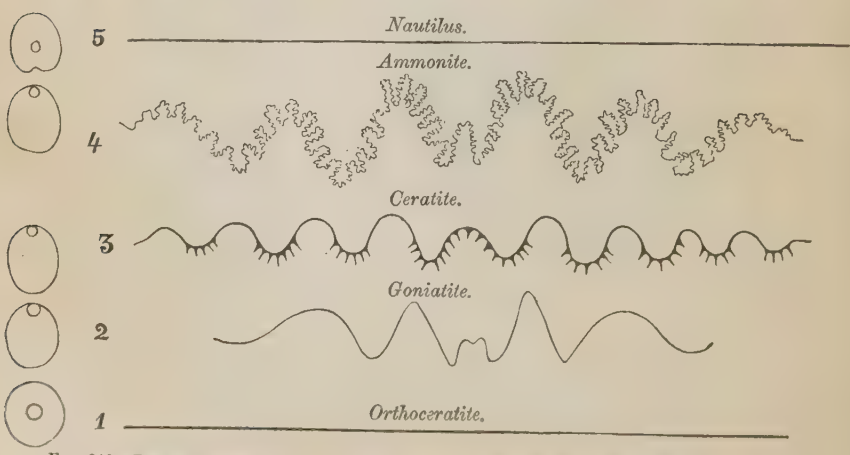


Fig. 646.—Diagram showing the Form of the Suture and the Position of the Siphon in Cephalopods.

genus, the edge of the septa, which was only plaited in Goniatite, and lobed in the Ceratite, becomes most elaborately *frilled.* We give above (Fig. 646) the form of suture in the type-genera of the different orders of shelled Cephalopods, the four lower in the order of their first appearance. In each case the suture is supposed to be divided on the ventral surface and spread out, so that the central part in the figure represents the dorsal portion, and the two extremities the ventral. In the Ammonite *family*, which includes the second, third, and fourth, the gradual evolution of this structure is well shown. The corresponding figures on the left are sections showing the position of the siphuncle.

The order in which these several genera appeared, and their continuance, are shown in the diagram (Fig. 656) on page 437.

Belemnites.—The Belemnite (*βέλεμνον, a dart*) was nearly allied to the squid and cuttle-fish of the present day. Like the squid, it had an internal bone (the pen of the squid), except that the bone is much larger and heavier in the Belemnite. It is this bone, or the lower portion of it, which is usually fossilized (Figs. 651–654). When perfect it is expanded and hollow at the upper end, and in the hollow is a small, coni-

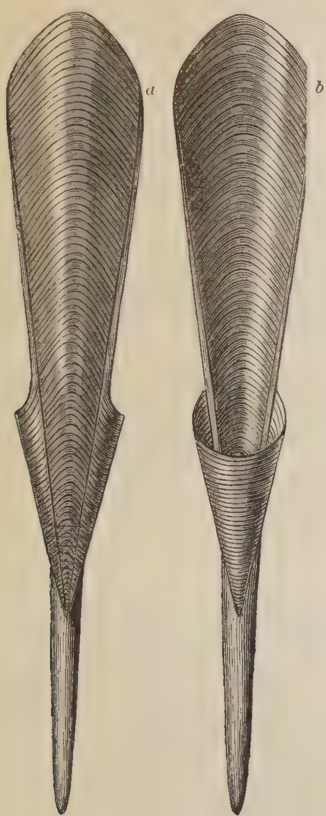


FIG. 647.

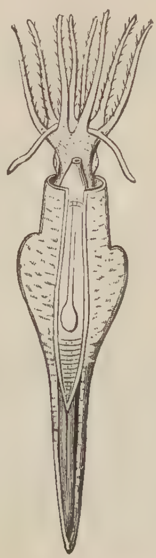


FIG. 648.

FIG. 649.

FIGS. 647–649.—647. Internal Shell of Belemnite (restored by d'Orbigny). 648. The Animal (restored by Owen). 649. A living Sepia for comparison.

cal, chambered, siphuncled shell, the *Phragmocone.* Fig. 647, *a* and *b*, shows the perfect bone, and Fig. 651 the upper part broken and the phragmocone in place. Like the squid, too, it had an ink-bag, from which it doubtless squirted the inky fluid to darken the water and escape its enemy. These ink-bags are often well preserved (Fig. 650), and the fossil ink has been found to make good pigment (sepia), and drawings of these extinct animals have actually been made with the fossil ink of their own ink-bags (Buckland). Belemnites were some of them of great size, and evidently formidable animals. The bone of the *Belemnites giganteus* has been found two feet long and three to four inches in

FIG. 650.—Fossil Ink-Bags of Belemnites.

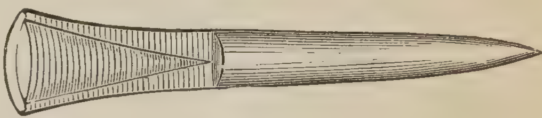


FIG. 651.—Belemnites Owenii.

diameter at the larger or hollow end. A very perfect specimen of an allied genus, from the Oölite of England, is shown in Fig. 655.

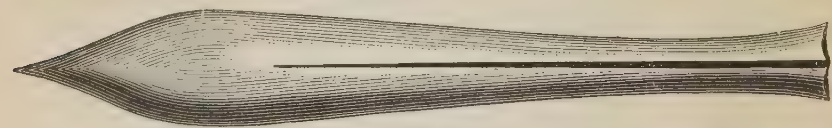


FIG. 652.

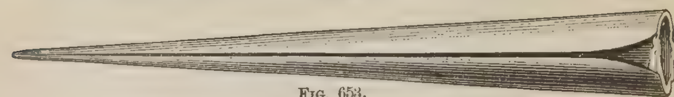


FIG. 653.

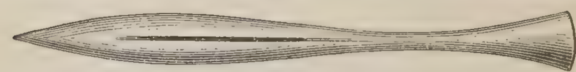


FIG. 654.

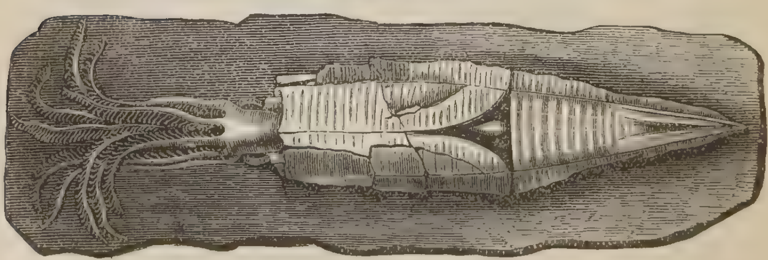


FIG. 655.

FIGS. 652–655.—652. Belemnites hastatus. 653. Belemnites unicanaliculatus. 654. Belemnites clavatus 655. Acanthoteuthis antiquus (after Mantell).

The following diagram shows the order of succession of families of the class Cephalopoda:

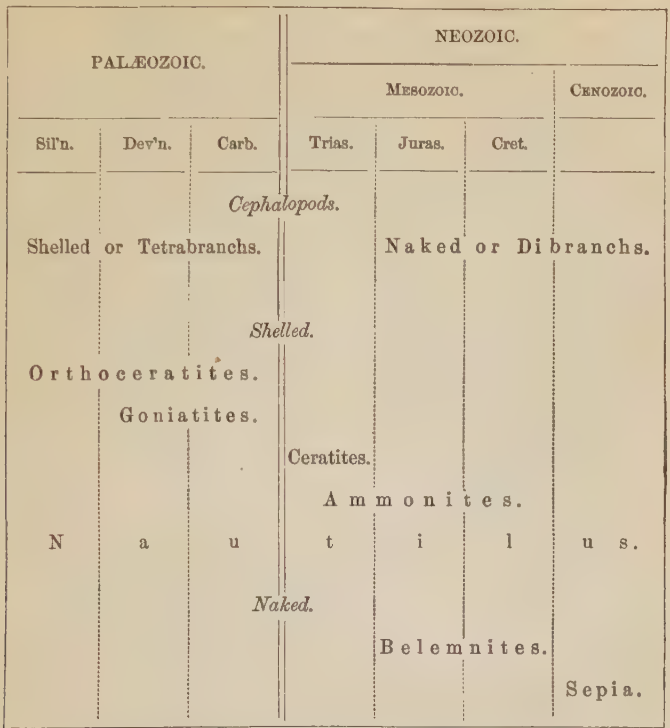


FIG. 656.—Diagram showing Distribution of Cephalopods in Time.

Crustacea.—Crustacea were represented in the Palæozoic first by the Trilobites; then Limuloids; then, in the last period, by a few Macrourans. In the Triassic the Macrourans became more abundant and of more modern type. In the Jurassic, the Macrourans continue, with also many Limuloids, but the former make here a decided approach to the Brachyourans or true crabs, by the shortening of the tail in some (Fig. 657); and the earliest true crab, Palæinachus—a spider-crab—has been found in the Jurassic of England.

Insects.—As might be expected from the abundant forest vegetation, insects have been found in considerable numbers and variety (Figs. 659–663). According to Heer, 143 species of insects are known from the Lias alone. Of these, about three-fourths are beetles.

Fishes.—It will be remembered that the Placoids of the Palæozoic were nearly all Cestracionts, or crushing-toothed sharks. The Hybodonts, or sharks with teeth pointed, but rounded on the edges, commenced in the Carboniferous, or perhaps Devonian, and increased in the Triassic. Now, in the Jurassic the Cestracionts continue (Fig.

664), but in diminished numbers. The Hybodonts culminate (Fig. 665), and the *Squalodonts*, or modern sharks, with lancet-shaped teeth, commence in small numbers. Rays (Fig. 666), which may be regarded

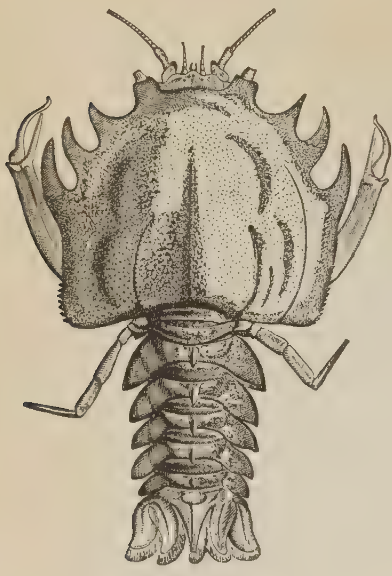


Fig. 657.

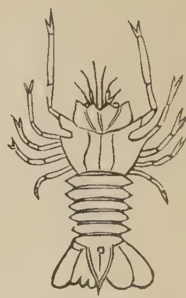


Fig. 658.

Fig. 659.

Figs. 657-659.—Jurassic Crustaceans and Insects: 657. Eryon arctiformis, Solenhofen. 658. Eryon Barrovensis, England. 659. Æschna eximia (Hager).

as among the highest of Placoids, are found in considerable numbers in the Jurassic.

Ganoids continue, but take on far more modern forms, and have now in most cases lost the vertebrated structure of the tail-fin, thus foreshadowing the Teleosts, which appear in the next period. Among the

most characteristic Ganoids of this period, and, in fact, of this age, are

FIG. 660.

FIG. 662.

FIG. 661.

FIG. 663.

FIGS. 660–663.—JURASSIC INSECTS: 660. Libellula. 661. Libellula Westwoodii. 662. Hemerobioides giganteus. 663. Buprestidium.

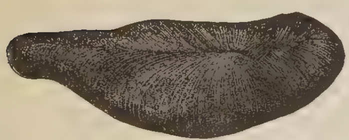


FIG. 664.

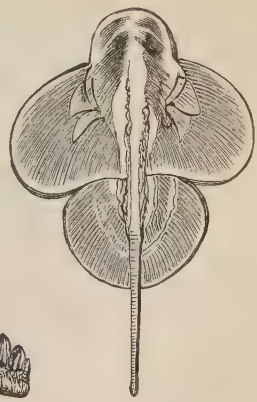


FIG. 666.

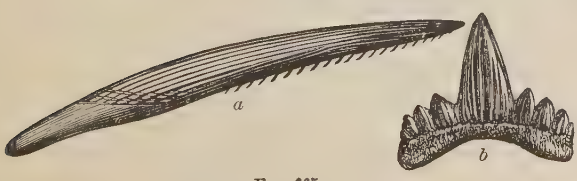


FIG. 665.

FIGS. 664–666.—JURASSIC FISHES—*Placoids:* 664. Tooth of Acrodus nobilis. 665. Hybodus reticulatus, Spine and Tooth. 666. Squatina acanthoderma.

the Pycnodonts, a family characterized by a broad, flat body, rhomboidal enameled scales, pavement palatal teeth, and persistent notochord (Fig. 667).

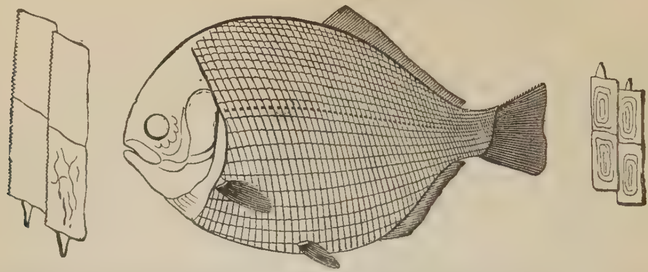


FIG. 667.—JURASSIC FISHES—*Ganoid;* Tetragonolepis, restored, and Scales of the same.

Reptiles.—The huge reptiles which form the distinguishing feature of this age culminate in the Jurassic period. Their number and variety are so great that we can only select a few from each order

FIG. 668.

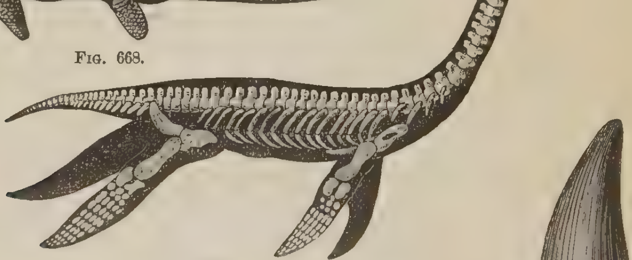


FIG. 669.

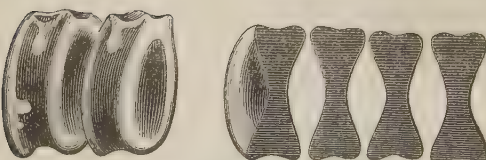


FIG. 670.

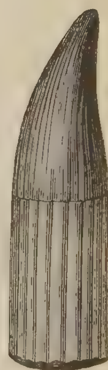


FIG. 671.

FIGS. 668-671.—JURASSIC REPTILES—*Ichthyosaurus and Plesiosaurus;* 668. Ichthyosaurus communis, × $\frac{1}{100}$. 669. Plesiosaurus dolichodeirus, restored, × $\frac{1}{80}$. 670. Vertebræ of Ichthyosaurus and Section of same, showing structure. 671. Tooth of Ichthyosaurus, natural size.

for description. They were emphatically rulers in every department of Nature—rulers of the sea, of the land, and of the air. We shall treat of them under the three heads thus indicated, viz.: 1. *Enalio-*

saurs (sea-saurians), or rulers of the sea; 2. *Dinosaurs* (huge saurians), or rulers of the land; and 3. *Pterosaurs* (winged saurians), or rulers of the air. The first were wholly swimming, the second walking, the third flying, saurians. Intermediate between the first and second was a fourth order, the *Crocodilians*, which both swam and crawled.

1. *Enaliosaurs.*—From the immense variety of these we select only two for description as representative genera, viz., *Ichthyosaurus* and *Plesiosaurus.* Figures of these are given on page 440.

The *Ichthyosaurus* (*fish-saurian*) was a huge animal, in some cases thirty to forty feet in length, with a stout body, short neck, and enormous head, sometimes five feet long, and jaws set with large conical, striated teeth, sometimes 200 in number. The enormous eyes, sometimes fifteen inches in diameter, were provided with radiating, bony plates, as are the eyes of birds and some living reptiles, apparently for adjusting the eye to different distances. The tail was long, and probably provided terminally with a *vertical, fin-like expansion*, unsupported by rays (Owen). In addition to the powerful fin-tipped tail, the locomotive organs were four short, stout paddles, composed of numerous closely-united bones, but without distinct toes. These paddles were surrounded by an expanded, ray-supported web (Fig. 672), which greatly increased its surface, and therefore its efficiency as swimming-organs (Lyell). The bodies of the vertebræ were not united by *ball-and-socket* joint, as in most living reptiles, but were *bi-concave* (amphicœlous), like those of fishes (Fig. 670).

FIG. 672.—Paddle-Web of an Ichthyosaurus.

That the *habits* of the creature were predatory and voracious is sufficiently attested by the teeth. It is further proved by the contents of the stomach, which are sometimes partly preserved. These consist largely of *fish-scales.*

From the description given above it is plain that the Ichthyosaurus combined in a remarkable degree the characters of saurian reptiles with those of fishes. The vertically expanded tail-tip, the paddles, with sur-

rounding ray-supported web, and the bi-concave vertebral bodies, are all decided fish characters. In most other respects it was reptilian. This combination is expressed in the name.

The *Plesiosaurus* (allied to a saurian) was a less heavy and powerful animal than the last. It was remarkable for its short, stout, almost turtle-shaped body; its long, snake-like neck, consisting of twenty to forty vertebræ; its small head; its short tail, unadapted for powerful propulsion; its long and powerful paddles, which were its sole swimming-organs; and its bi-concave vertebral bodies. Sixteen species have been found in the Jurassic and Cretaceous rocks of Great Britain alone, and one, *P. dolichodeirus*, was twenty-five to thirty feet long (Fig. 669), with paddles six to seven feet long.

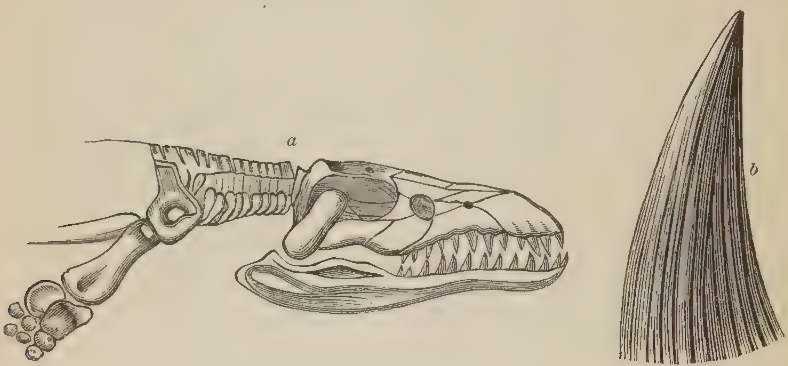


FIG. 673.—*a*, Head of a Pliosaurus, greatly reduced; *b*, Tooth of a Pliosaurus, natural size.

The *Pliosaurus* (more lizard-like) had the large head and short neck of the Ichthyosaurus (Fig. 673), with the powerful paddles of the Plesiosaurus. A perfect paddle of this animal has been found seven feet long (Fig. 674); the animal was probably at least forty feet long.

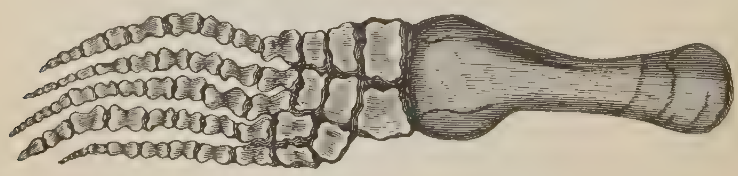


FIG. 674.—Paddle of a Pliosaurus, $\times \frac{1}{25}$.

Intermediate between this group and the next—inhabiters both of land and water—*Crocodilians* existed in great numbers, and of great size. Some, like the Teleosaurus (Fig. 675), were narrow-snouted like the Gavials of the Ganges, but had amphicœlous vertebræ like the Enaliosaurs.

2. *Dinosaurs.*—These reptiles were the most highly organized in structure, as they were certainly the hugest in size, which have ever existed. Though very decided reptiles, they combined certain characters which allied them somewhat with mammals and especially with birds. Their very large, long, and hollow limb-bones, their strong, massive hip-bones and sacrum, the latter composed of *several consolidated vertebræ,* allied them with both mammals and birds; while the great elonga-

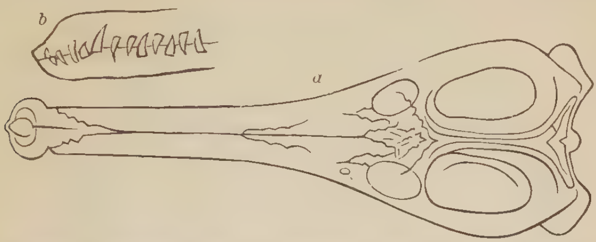


FIG. 675.—Teleosaurus brevidens: *a*, skull; *b*, side-view of snout showing the teeth (after Phillips).

tion backward of the ischium, the massiveness of the hind-legs as compared with the fore-legs, and the possession of only three functional toes on the hind-foot, which therefore formed a *tridactyl track*, allied them still more strongly with birds. On account of this great likeness to birds in the character of the hind-limbs, they have been called by Prof. Huxley *Ornithoscelida* (bird-legged). The following figures (676, 677) illustrate this bird-like character.

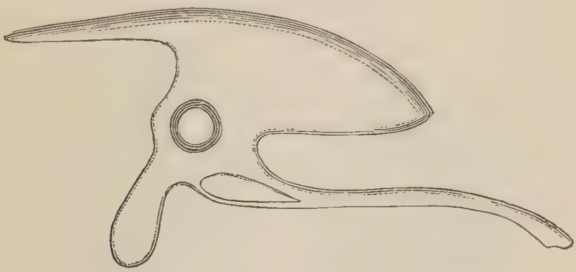


FIG. 676.—Pelvis of an Iguanodon (restored by Hulke).

It seems certain that all the Dinosaurs *walked* with free step, like quadrupeds, instead of *crawling*, like reptiles; and some if not all of them, had the power of standing and *walking on their hind-legs alone, like birds.* The backward elongation of the ischiatic bones seems evidently connected with the erection of the body on the hind-legs. We will briefly describe only the most remarkable:

The *Iguanodon* was a huge herbivorous Dinosaur, found principally in the Wealden (Upper Jurassic). It takes its name from the form of

its teeth, which are much like those of the Iguana, a living herbivorous reptile, although in other respects there is little affinity. Fig. 678

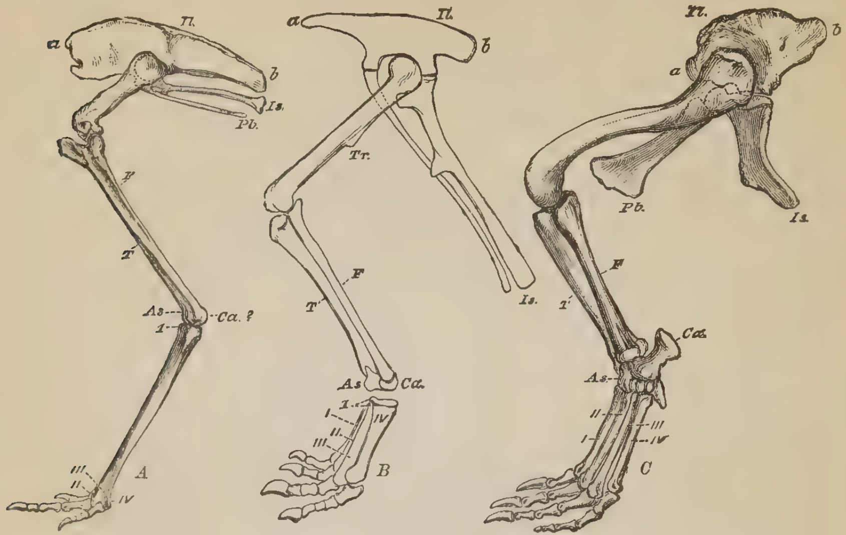


Fig. 677.—*A*, Dromæus; *B*, Dinosaur; *C*, Crocodile.

shows the tooth of the Iguanodon, and Fig. 679 a section of the jaw of the Iguana, for comparison.

But the difference in size between the living and the extinct reptile

Fig. 678.—Tooth of an Iguanodon.

is enormous. The Iguana is from four to six feet long; the Iguanodon was certainly thirty feet, perhaps fifty or sixty feet long, and of bulk

several times greater than that of an elephant. A thigh-bone has been found fifty-six inches long, twenty-two inches in circumference at the shaft, and forty-two inches at the condyle. Its habits are supposed to have been somewhat like those of a hippopotamus. Like this animal, it wallowed in the mud, and fed on the rank herbage of marshy grounds.

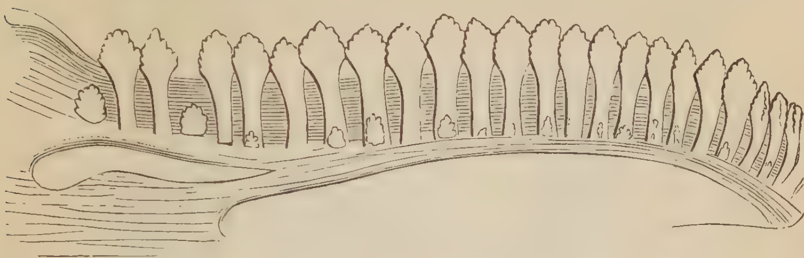


FIG. 679.—Section of Jaw of an Iguana, showing the teeth (after Buckland).

The *Megalosaur* was a somewhat smaller but probably a more formidable carnivorous reptile, which lived through the whole Jurassic period. Its huge jaws were armed with large, curved, flattened, sabre-like teeth (Fig. 681). A femur has been found forty-two inches long (Phillips), and a tibia thirty-six inches. The animal was at least thirty feet long (Owen). Fig. 680 is a restoration of the head of this animal by Phillips, and Fig. 681 is a tooth of natural size.

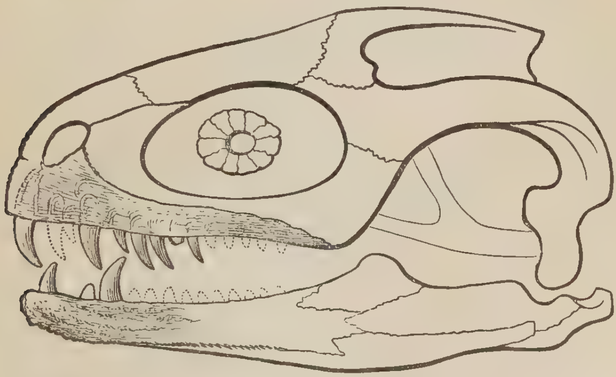


FIG. 680.—Head of Megalosaurus, × $\frac{1}{10}$ (restored by Phillips).

The *Ceteosaur* (whale-lizard) was the largest reptile yet found in Europe, though much larger have been found in the Jurassic of the United States. It has been classed among the Crocodilians, but Prof. Phillips has shown that its true position is among the Dinosaurs. A thigh-bone has been found sixty-four inches long, 27.5 inches in circumference at the shaft, forty-six inches

FIG. 681. — Megalosaurus Tooth, natural size (after Phillips).

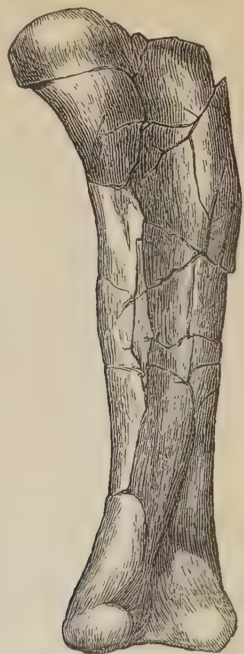


FIG. 682.—Femur of Ceteosaurus, $\times \frac{1}{20}$ (after Phillips).

and 44.25 inches in circumference at the two ends, respectively (Fig. 682). According to Phillips this animal was at least fifty feet, and probably from sixty to seventy feet long, ten feet high when standing, and of bulk proportionate. It was probably a vegetable feeder.

FIG. 683.—Compsognathus (restoration by Huxley).

The *Hylæosaur* was another huge reptile of the same period, and the *Compsognathus* a reptile of smaller size, but of most extraordinary bird-like character, viz., small head, long, flexible neck, large and long hind-legs, and small and short fore-legs. From its structure, it must have walked habitually on its hind-legs alone (Fig. 683).

3. *Pterosaurs.*—These flying reptiles were certainly among the most extraordinary animals that have ever existed. The order includes sev-

eral genera, but we will describe only the best known, viz., the *Pterodactyl* (wing-finger).

The Pterodactyl combined the short, compact body; the strong shoulder-girdle, firmly united with the keeled sternum; the short, aborted tail; the long, flexible neck, and hollow, air-filled limb-bones,

FIG. 684.—Rhamphorhynchus phyllurus (after Marsh).

characteristic of birds—with the head, and jaws, and teeth, of a reptile, and the membranous wings of a bat. In the bat, however, the membrane is supported by *four* fingers, enormously elongated for the purpose, and only one finger is *free* and *clawed;* while in the Pterodactyl there is only one finger, which is enormously elongated and strengthened for the support of the web, and the others are free and clawed.

FIG. 685.—Restoration of Rhamphorhynchus phyllurus (after Marsh). One-seventh natural size.

The fossil remains of one species (*Rhamphorhynchus phyllurus*), as found in the Solenhofen lithographic limestone, are shown in Fig. 684. In the restoration by Professor Marsh, Fig. 685, is shown the manner in which the wing membrane is stretched from the elongated finger.[1]

[1] See APPENDIX.

Birds.—Until recently, except the doubtful tracks of the Connecticut Valley, to be mentioned further on, no trace of birds had been found lower than the Tertiary. But in 1862 bird-bones and beautiful impressions of bird-feathers were found in the lithographic limestone (Upper Oölite—Jurassic) of Solenhofen. Still later, many remains of birds were found by Marsh in the Cretaceous of the United States. These will be described in their proper place.

Thus far the only bird-bones found in the Jurassic are those of the *Archæopteryx* (ancient bird), and the *Laopteryx* (stone-bird), recently found by Marsh in the Rocky Mountains. These remains are the earliest positive proof of the existence of this class; they are therefore

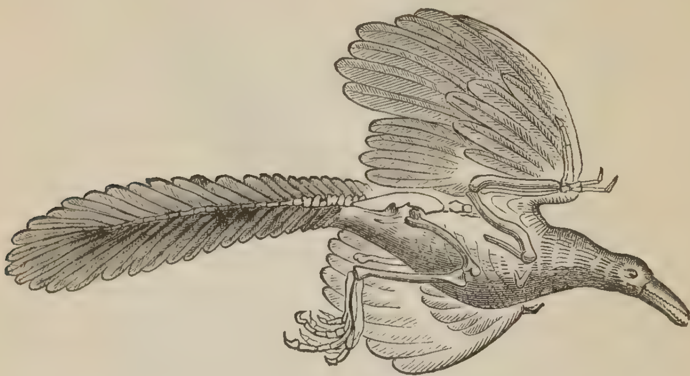


Fig. 686.—Archæopteryx macroura, restored (after Owen).

of exceeding interest to the geologist. An examination of the figures below (Figs. 687, 688) will show that this earliest bird was very different from the typical birds of the present day; that it was, in fact, wonderfully *reptilian*. Along with the distinctive bird characters of feet and limb-bones and pelvis, and especially feathers and *feathered wings*, it had the *long tail* and probably *toothed jaws* of a reptile. The difference between the tail of a typical bird and the tail of the Archæopteryx is very similar to the difference between a homocercal and a heterocercal tail among fishes. In a typical bird the tail-joints are greatly shortened and consolidated, so that it is not more than an inch long in a bird the size of a cock; and the tail-feathers come out from these in a radiating manner (Fig. 687, *D*). In the Archæopteryx, on the other hand, the tail consists of twenty-one long joints; making the tail of the skeleton eight or nine inches long, nearly or quite as long as all the rest of the skeleton; and to these joints are attached the feathers, one on each side of each joint (Fig. 687, *A*). It is a true *vertebrated tail.*

Another very striking reptilian character is found in the structure of the *hand.* In ordinary birds what corresponds to the hand consists of three fingers, two of which are united, and only one (the thumb) is

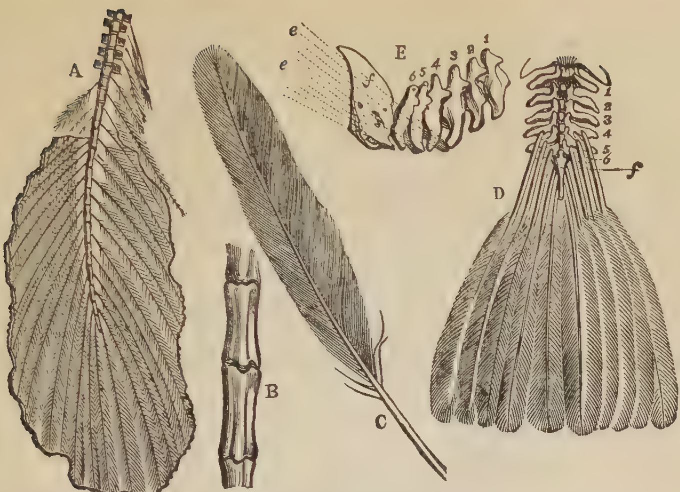


FIG. 687.—*A*, Tail of Archæopteryx macroura; *B*, Vertebræ enlarged; *C*, a Feather; *D*, Tail of a Vulture; *E*, side-view of the same.

free; but in this earliest bird the hand consists of three fingers, all separate, and two of them terminated with claws.[1]

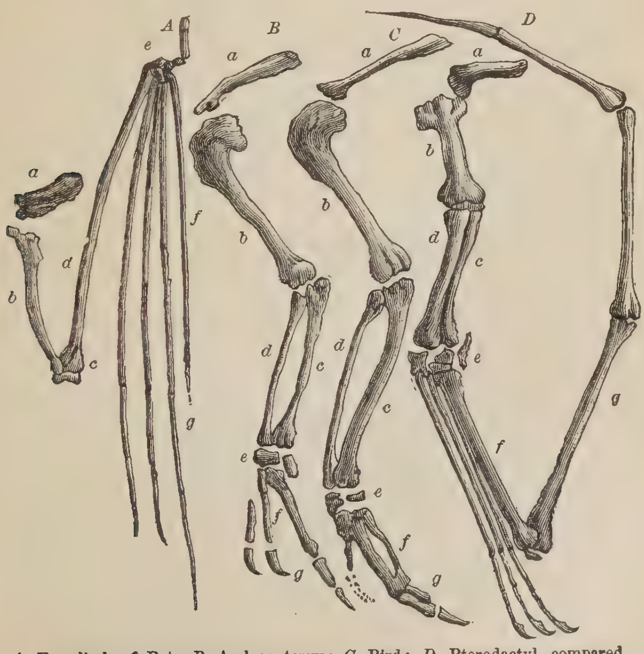


FIG. 688.—*A*, Fore-limb of Bat; *B*, Archæopteryx; *C*, Bird; *D*, Pterodactyl, compared. In all—*a*, scapula; *b*, humerus; *c*, ulna; *d*, radius; *e*, carpus; *f*, metacarpus; *g*, phalanges.

[1] See APPENDIX.

Mammals.—In the same formation and nearly the same horizon in which we find the *dirt-bed* and stumps mentioned on page 428 (Upper Oölite) have been found also in England the remains of fourteen species of small insectivorous Marsupial mammals, varying in size from that of a mole to that of a skunk. It would seem, therefore, that we have found not only an old forest-ground of the Jurassic period, but also the trees which grew in, and the animals which roamed through, this old forest. In a somewhat lower bed, the *Stonefield slate* of England, have been found four more species. To these must now be added seventeen new species recently discovered by Marsh in the uppermost Jurassic deposits of the United States, making in all thirty-five species of Jurassic mammals now known. Still lower, in uppermost Triassic, have been found in all countries taken together two or three more.

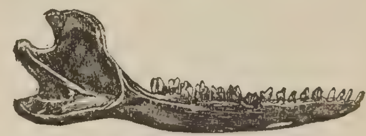


Fig. 689.

Fig. 690.

Fig. 691.

Fig. 692.

Fig. 693.

Figs. 689–693.—Jurassic Mammals: 689. Amphitherium Prevostii. 690. Phascolotherium. 691. Amphitherium. 692. Triconodon. 693. Plagiaulax.

They were probably *Marsupials;* and, with the exception of one which, judging by its rodent teeth, was possibly a vegetable-feeder, they all seem to have been *insectivorous.*

Affinities of the First Mammals.—The marsupials differ very greatly from ordinary typical mammals, in the fact that in the former there is no placental attachment between the *fœtus in utero* and the mother. The fœtus, therefore, does not and cannot develop before birth into a perfect condition fit for independent life. In an imperfect condition it is born and placed in an abdominal pouch (marsupium), *permanently* attached to the teat, and *finishes its embryonic development there.* Thus in these animals there are *two periods of gestation*, one *intra-uterine*, very short, and another *marsupial*, much longer. Marsupial mammals, therefore, are not truly viviparous, but semi-oviparous, in their

reproduction, and in this respect allied to *birds* and *reptiles.* The class of Mammals is therefore subdivided into two sub-classes, viz., Placental or true mammals and Non-placental or semi-oviparous mammals. The former includes all ordinary mammals; the latter at present includes kangaroos, opossums, etc. (Marsupials), and Ornithorhynchus and Echidna (Monotremes).

Now, the mammals of the Triassic and Jurassic were probably non-placental or semi-oviparous, and therefore approximated the lower classes of Vertebrates, especially birds and reptiles. The non-placentals are now (with the exception of a few species of opossum found in America) wholly confined to Australia and the vicinity. In Jurassic times they were probably very abundant, and spread over all portions of the earth. Yet they were not rulers of those times; for they were wholly unable to contend with the great reptiles. It was essentially an age of Reptiles. Not only did this class greatly predominate in number and size, but the reptilian character was strongly impressed on all the then existing birds and mammals. From the reptilian *stem* the *bird and mammal branches had not yet so fairly separated* that the connecting links were obliterated.

Section 3.—Jura-Trias in America.

We have already explained that these two periods are not well separated in America. This is partly on account of the poverty of fossils, and partly on account of the continuity of conditions throughout. It seems best, therefore, in the present state of knowledge to treat them together as one period. Doubtless they will be better separated hereafter.

Distribution of Strata.—1. *Atlantic Border.*—Lying in plication-hollows, or denudation-hollows, unconformably on the gneiss (metamorphic Laurentian or Silurian) of the eastern slope of the Appalachian chain, are found very remarkable isolated patches of sandstones or sandstones and shales, which are referred to this period. These patches are strung along nearly parallel to the chain, and to the coast, from Nova Scotia to the border of South Carolina. They are represented on the map (p. 289) by oblique lines. One of them is found in Prince Edward's Island, another in Nova Scotia; another is the celebrated Connecticut River Valley sandstone; a fourth commences in New Jersey, passes as a narrow strip through Pennsylvania, Maryland, and into Virginia; a fifth and sixth form the Richmond and Piedmont coal-fields of Virginia; a seventh and eighth, the Dan River and Deep River coal-fields of North Carolina. As they are isolated, and without contact with any other formation except the gneiss, on which they lie unconformably, their age cannot be even conjectured from their stratigraphical relations; but the

few fossils which they contain seem to refer them either wholly to the Triassic, or else, more probably, their lower half to the *Triassic* and their upper half to the *Jurassic* of Europe (Hitchcock).

In connection with nearly all these patches are found columnar trap or dolerite ridges, evidently formed by the fissuring of the strata and the outpouring of igneous matter upon the surface. Mounts Tom and Holyoke are examples in the Connecticut Valley, the Palisades of the Hudson in the New Jersey patch; similar trap-ridges are also very conspicuous in the Nova Scotia patch.

2. *Interior Plains.*—Rocks of this age seem to be widely distributed on the eastern slopes of the Rocky Mountains, from the Black Hills southward, largely covered in the northern parts by Cretaceous, but exposed over wide areas south of the 38th parallel and west of the 97th meridian, including large portions of Kansas and Indian Territory, and Northern Texas.

3. *Rocky Mountain Region and Pacific Slope.*—Portions of the Black Hills, of the Colorado Mountains, of the Wahsatch range, and of the ranges of Western Nevada, consist of these rocks. Outcrops also occur on the slopes of the Uintah Mountains, and large areas in the plateau region north of Grand Cañon, forming several of the remarkable cliffs of that region, and also large areas in the valley of the Rio Grande, about Santa Fé, New Mexico. The auriferous slates of California, extending northward even into British Columbia, consist of the same.

Life-System.

The characterization of the life-system of the Jura-Trias period in America is best brought out in connection with a minuter description of some of the more interesting localities, and of their remarkable records.

Connecticut River Valley Sandstone.—The Strata.—This locality has been made classic ground for the geologist by the indefatigable labors of the late President Hitchcock, of Amherst. The strata border the Connecticut River, on both sides, through the whole of Massachusetts

FIG. 694.—A Section across the Valley of Connecticut: *g*, gneiss; *ss*, sandstone; *t*, trap-ridges.

and Connecticut, forming an irregular area about 110 miles long and 20 miles wide.[1] They consist of red sandstones and shales, dipping somewhat regularly to the east, at an angle of about 20° to 30°, indicating a thickness of at least 5,000 feet (Dana) to 10,000 feet (Hitchcock). The general relations of the strata with the intrusive trap and the underlying gneiss are shown in the accompanying figure (694). The trap is seen to

[1] More accurately, the river, about twenty miles from the sound, bends to the east and leaves the sandstone area, while the latter passes straight on to the sound at New Haven.

be mostly conformable with the strata. This regular dipping to the east throughout the whole series can only be explained by supposing that at the end of the Jurassic the whole area of previously-horizontal strata (Fig. 695, *A*) was lifted into an incline of 20° or more, and afterward cut away by denudation, as shown in the diagram (Fig. 695, *B*).[1]

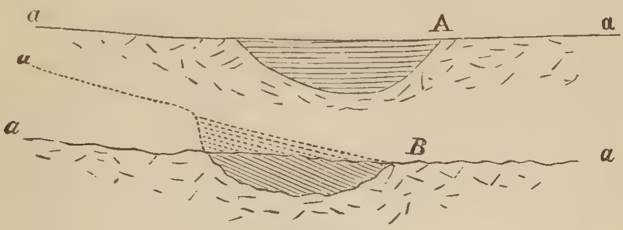


FIG. 695.

The whole series of sandstone is very distinctly stratified, and in many parts beautifully fissile. When these parts are broken open along their lines of lamination, all kinds of *shore-marks* are found in the greatest perfection, viz., *ripple-marks*, *rain-prints*, *sun-cracks*, *leaf-impressions*, and *tracks of animals.* It is evident, therefore, that this was, throughout, a *littoral or shoal-water deposit.* But it is at least 5,000 feet thick. Therefore, there must have been subsidence to that extent. Here, then, we have evidence of *rapid* deposit (for the materials are coarse), invasion of interior heat with *aqueo-igneous fusion*, *subsidence*, formation of *fissures*, and ejection of *lava.*

Some identifiable fossils, obtained about the middle of the series, seem to indicate an horizon similar to the Lias, lowest Jurassic; or to the Rhætic, uppermost Triassic of England. It is fair to conclude, therefore, that this patch represents the whole Jura-Trias period.

The Record.—The general *redness* of the sandstone is sufficient evidence that organic remains are very scarce; and so, indeed, we find it. Two or three fishes, a few leaves, the most perfect of which is a species of fern—Clathopteris—and a fir-cone (Fig. 696), and a few small fragments of thin, hollow bones, which may have belonged to either birds or reptiles, are all that have been yet found.

But by far the most interesting portion of the record in this locality consists of *tracks.* These are partly tracks of Insects and Crustaceans, and partly of Reptiles and, possibly, Birds. Some of

FIG. 696.—*a*, Frond; *b*, Cone (after Hitchcock).

[1] See APPENDIX.

those which have been referred to Crustaceans and Insects are shown in Fig. 697, *a*, *b*, *c*. There has been found, also, the whole form of one insect, apparently the larva of an Ephemera (Fig. 698). It is quite probable that many of the tracks were formed by similar larvæ inhabiting the water.

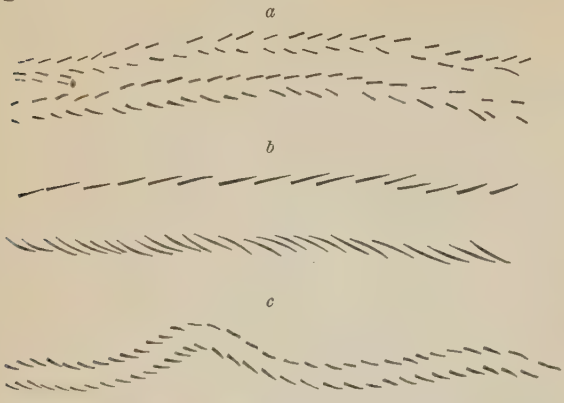


FIG. 697.—*a*, *b*, *c*, Tracks of Insects, Crustacea, or Worms (after Hitchcock).

FIG. 698.—Larva of an Ephemera (after Hitchcock).

Reptilian Tracks.—By far the larger number of tracks are those of Reptiles. More than fifty species have been described by Hitchcock. These vary extremely, both in size and in character. In *size*, they vary from the track of a living Triton, a half-inch long, to that of the Otozoum, twenty inches long, and with a stride of three feet. Some had five toes, some four, and some only three functional toes on the hind-feet. Again, some had hind and fore feet of nearly equal size, and evidently walked or crawled in true quadrupedal style. Others had hind-feet much larger than fore-feet, and were essentially bipedal in locomotion, only putting down their small fore-feet occasionally; but walking bird-like, not hopping kangaroo-like, on their hind-legs. In connection with the bipedal tracks there have been found what seemed to be the impression of a dragging tail (Fig. 700); but these are so rare and doubtful that it is generally believed the animals were mostly long-legged and short-tailed.

The general conclusion from an attentive study of these tracks, in connection with the findings elsewhere of bones and teeth, is that they are the tracks partly of Amphibians of the order of *Labyrinthodonts*, but most were probably Dinosaurs. The hugest among them, the *Otozoum Moodii* (Fig. 699), was probably a long-legged, biped amphibian, which stood twelve feet high. The *Anomœpus* (Fig. 701), a common form, was probably a *Dinosaur*, which walked often on two legs only, and in so doing brought the whole tarsus and heel on the

ground, in the manner of a kangaroo. In Fig. 700 the mark of a supposed dragging tail is shown.

Bird-Tracks.—Those which have been referred to birds are: 1. *Wholly bipedal*, i. e., there is no evidence of fore-feet at all. 2. They are *tridactyl*. 3. They have a regular progression in the number of joints in the tracks, the inner toe having two, the middle toe three, and the outer toe four *joints*. Now, in birds the inner toe has three, the middle toe four, and the outer toe five joints, but the last two joints

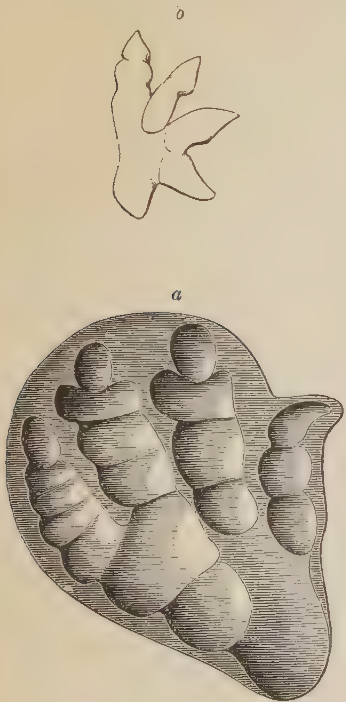


Fig. 699.

Fig. 700.

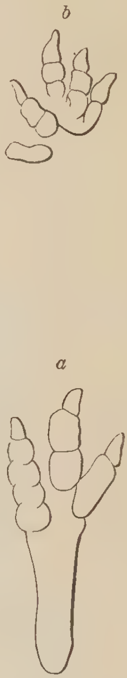


Fig. 701.

Figs. 699–701.—Reptile-Tracks (after Hitchcock): 699. Otozoum Moodii: *a*, hind-foot, × $\frac{1}{10}$; *b*, fore-foot, × $\frac{1}{10}$. 700. Gigantitherium caudatum, × $\frac{1}{30}$. 701. Anomœpus minor, × $\frac{1}{8}$: *a*, hind-foot; *b*, fore-foot.

in each case make but one division of the track, so that the track is exactly what is given above. The discovery, however, that Dinosaurs have but three functional toes on the hind-foot, and that they also have the same number of joints as birds, has greatly shaken confidence in the ornithic character of these tracks. Only the absence of fore-feet tracks, therefore, remains. But as many of these early reptiles walked *occasionally* on two legs, it is not impossible that *some* of them *always* walked thus. It is quite possible, not to say probable, therefore, that all these tracks are those of Reptiles. Assuming them to be those of

Birds, they varied in size from those of a snipe to those of the great *Brontozoum*, eighteen inches long, and with a stride of four feet (Fig. 702). This huge bird, if bird it was, must have been at least fourteen feet high (Dana). Such a huge animal must have been wingless, like the ostrich, etc., for its size is far beyond the limit within which flight is possible.

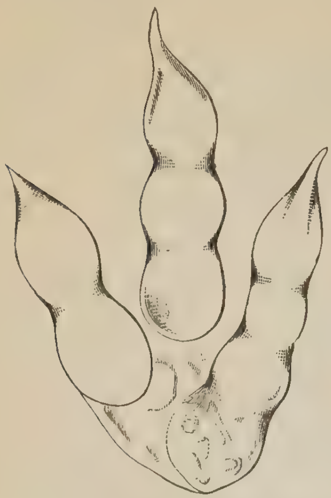


FIG. 702.—Track of Brontozoum giganteum, × ⅛ (after Hitchcock).

We have expressed a doubt as to whether these tracks be those of birds or reptiles. This is not so strange as it may at first appear. These two classes are, indeed, *now* very widely separated; but *then* they were very closely allied. There were probably animals then living which, even if we saw them, might puzzle us to decide whether to call them reptilian birds or bird-like reptiles. *These two classes were not yet fairly disentangled and separated from each other.*

We may easily imagine the circumstances under which these tracks were formed. During the Jura-Trias period there was in the region of the Connecticut Valley a shallow inland sea, connected by a narrow

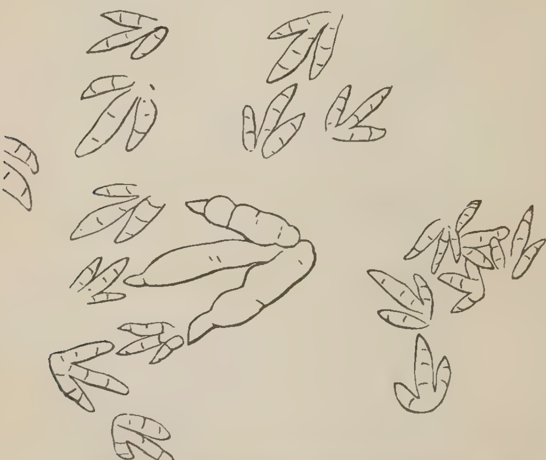


FIG. 703.—Portion of a Slab with Tracks of several Species of Brontozoum (after Hitchcock).

outlet with the ocean. Into this the tides flowed and again ebbed, leaving extensive flats of mud or sand ribbed with ripple-marks. A pass-

ing shower pitted the soft mud, and the sun, coming out again from the breaking clouds, dried and cracked it. Huge bird-like reptiles, and possibly reptilian birds, sauntered near the shore-margin in search of food. The tide came in again with its freight of fine sediments, gently covered the tracks, and preserved them forever. This occurred constantly for many ages about the end of the Triassic or the beginning of the Jurassic period, for the tracks are found near the middle of the series of strata.

Richmond and North Carolina Coal-Fields.—The patches occurring in Virginia and North Carolina are *coal-bearing*. They constitute the Richmond and Piedmont coal-fields of Virginia, and the Deep River and Dan River coal-fields of North Carolina. Fig. 704 gives a general-

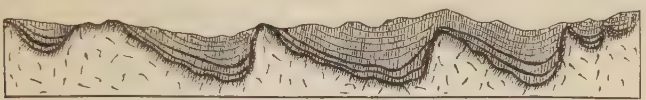


Fig. 704.—Section across Richmond Coal-field (after Daddow).

ized section of the Richmond coal-fields, taken from Daddow. The strata of this field are sandstone and shales, 700 to 800 feet thick, lying in irregular erosion-hollows of the gneiss. All the phenomena of a coal-field are here repeated, viz., interstratified seams of *coal* and beds of *iron-ore*, *underclays* with roots, and *roof-shales* with leaf-impressions. There are several seams of coal, the lowest of which is almost in contact with the gneiss. Some of the seams are of great thickness—thirty to forty feet—and the coal is very pure. It is probable that this coal, like that of the Carboniferous times, was formed in a marsh, which was sometimes converted into a lake. The plants found are

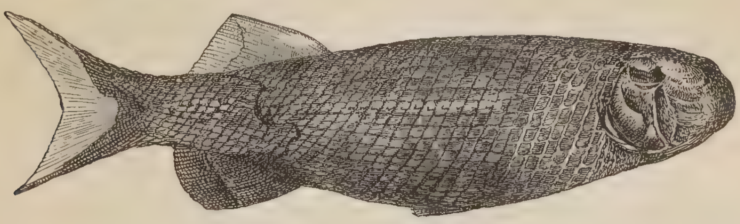


Fig. 705.—Catopterus, a Ganoid (after Emmons).

very decidedly Upper Triassic or Lower Jurassic, viz., Cycads, Conifers, Equisetæ, and Ferns. The animals indicate the same horizon.

The Deep River and Dan River coal-fields of North Carolina are very similar to those in Eastern Virginia, except that in the Deep River coal-fields the coal-bearing portion, which seems to correspond with the whole of the Richmond strata, is underlaid by 3,000 feet of barren sandstone. If we call the coal-measures Upper Trias or Lower Juras,

these barren sandstones are certainly Triassic. In their upper portion,

Fig. 706.

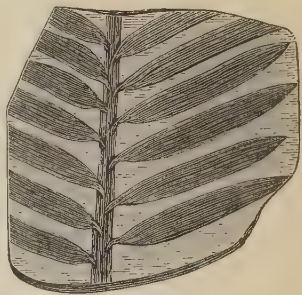


Fig. 707.

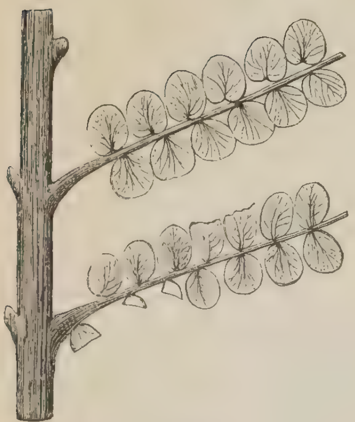


Fig. 708.

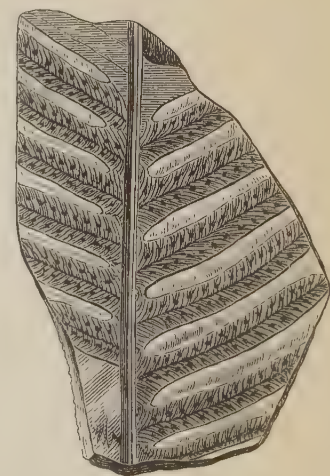


Fig. 709.

Fig. 710.

Fig 711.

Figs. 706–711.—Fossils of North Carolina and Richmond Coal-Basins (after Emmons): 706. Walchia diffusus. 707. Podozamites Emmonsi. 708. Neuropteris linæfolia—Richmond Coal. 709. Pecopteris falcatus. 710. Neuropteris. 711. Jaw of Dromatherium sylvestre.

hence probably in the Upper Triassic, Emmons found jaws of a Marsupial, which he names *Dromatherium sylvestre.* Until the recent discoveries of Marsh, this was the only mammal known from the Jura-Trias of America. We give on pages 457 and 458 figures of the plants and animals of these two basins. Tridactyl tracks like those in Connecticut have also been found in New Jersey.

Other Patches.—In other patches, especially in New Jersey, Pennsylvania, and Nova Scotia, reptilian bones and teeth have been found, representing Dinosaurs, and Crocodilians or Lacertians. The jaw and

Fig. 712.

Fig. 713.

Fig. 714.

Figs. 712–714.—Reptiles: 712. Bathygnathus borealis, reduced (after Dawson); *a*, fifth tooth, natural size; *b*, cross-section of a tooth. 713. Belodon Carolinensis (after Emmons). 714. Clepsysaurus Pennsylvanicus (after Emmons).

teeth of a huge reptile, Leidy's *Bathygnathus* (*deep jaw*), were found in Nova Scotia. The teeth were four inches long. Cope makes it a Dinosaur; Leidy an Amphibian; Owen refers it to his order of Theriodonts.

Interior Plains and Pacific Slope.—The Jura-Trias of the interior plains are singularly deficient in fossils. The gypsum in many of them furnishes the explanation. They were probably formed in interior and

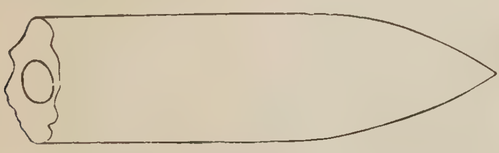


Fig. 715.

Fig. 716.

Figs. 715 and 716.—Jurassic Fossils of Utah (after Meek): 715. Belemnites densus. 716. Gryphæa calceola.

very salt seas, which are usually deficient in life. The two periods are, however, in some places at least, better separated than on the Atlantic slope, probably because of more variable conditions.

Fig. 717.

Fig. 718.

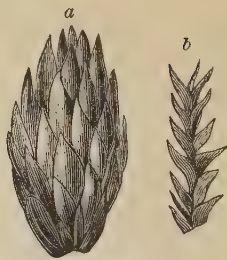


Fig. 719.

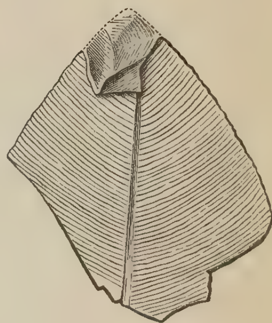


Fig. 723.

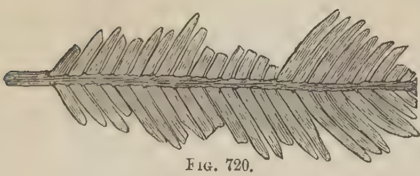


Fig. 720.

Fig. 721.

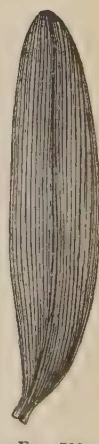


Fig. 722.

Fig. 724.

Figs. 717-724.—Plants of the Jura-Trias (after Newberry): 717. Branch of Conifer (Brachyphyllum). 718. Branch of Conifer. 719. Conifer, Branch and Fruit. 720. Zamites occidentalis. 721. Otozamites Macombii. 722. Podozamites crassifolia. 723. Tæniopteris elegans. 724. Alethopteris Whitneyi.

On the slopes of the Black Hills and on the South Platte undoubted Jurassic fossils occur, indicating an open sea. In New Mexico Newberry found impressions of plants, indicating the same horizon as in North Carolina and Virginia—i. e., Upper Triassic. Some of these are given (Figs. 717–724).

On the Pacific coast, marine life, no doubt, abounded, as this was the margin of an open sea; but the rocks here are mostly very highly metamorphic, and the fossils, therefore, mostly destroyed. Wherever this is not the case, the rocks abound in fossils. In Humboldt County, Nevada, for example, the strata in some places seem almost wholly made up of Ceratites Whitneyi (Fig. 727). In the same locality the remains of an Enaliosaur (sea-saurian) have been found. On account of the marine conditions prevalent, the two periods are easily separable on the Pacific coast.

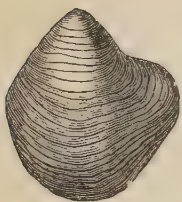


Fig. 725.

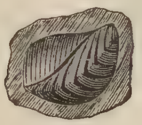


Fig. 726.

Fig. 727.

Figs. 725–727.—California Jura-Trias Shells: 725. Gryphæa speciosa (after Gabb). 726. Trigonia pandicosta (after Gabb). 727. Ceratites Whitneyi (after Gabb).

Recent Discoveries.—Very recently in Colorado and Wyoming, in beds which are referred to the uppermost Jurassic deposits, a large number of most extraordinary reptiles have been found and described by Marsh and Cope. Also, in the Wyoming beds, Marsh has discovered some seventeen species of Marsupial mammals and a reptilian bird (*Laopteryx*). The beds from which all these have been taken are called, from their most abundant and characteristic form, the *Atlantosaur beds.* These important discoveries require some notice here.

Dinosaurs.—The most abundant and the largest reptiles found here are Dinosaurs. Some ten or twelve species of this order have been described by Cope, and fifteen or twenty species by Marsh. Some of these are from the east slope of the Colorado Mountains, but the most important have been found on the west slope. In the museum of Yale College there are now the remains of several hundred individuals. These American Jurassic Dinosaurs were probably the largest land animals that have ever lived. Cope describes one (Camarasaurus)

with a thigh-bone six feet long. Marsh describes one (Atlantosaurus immanis) with thigh-bone about eight feet long.[1] Along with these

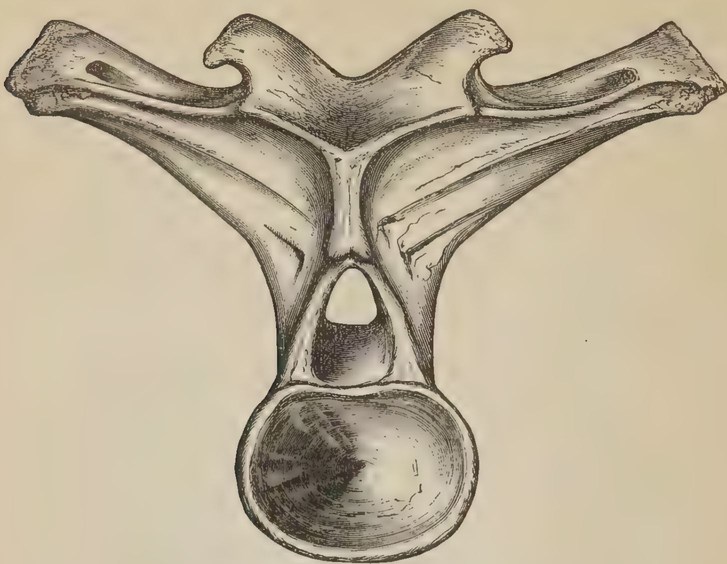


FIG. 727a.—Dorsal vertebra of Camarasaurus, reduced (after Cope).

huge animals lived also the smallest Dinosaurs yet known—one of them, Nanosaurus agilis, being about the size of a cat.

The characteristics of these ancient reptiles have been worked out with great skill by Marsh, according to whom the vertebræ of many of them were full of large cavities, so as to make these enormous bones as light as possible. This character reached its highest expression in *Cœluria* of Marsh (Fig. 727b). According to the same authority, the American Jurassic Dinosaurs are some of them Saurian-footed (Sauropoda) plantigrade, some bird-footed (Ornithopoda), some beast-footed (Theropoda), and some belong to a new and very remarkable order Stegosauria (plate-covered). Among the Sauropoda the most remarkable were the huge Atlantosaurus, the Brontosaurus, the Morosaurus (Fig. 727c), and the Apatosaurus. The firmness of the pelvis, with a sacrum of four consolidated vertebræ, and the structure of the powerful limbs, are well shown in these figures. Among the bird-footed

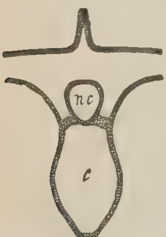


FIG. 727b.—Dorsal vertebra of *Cœlurus fragilis*, transverse section (after Marsh).

[1] See APPENDIX.

kinds, the Laosaurus (Fig. 727d) and the Camptonotus (Fig. 727e) are excellent examples. The great disparity between hind and fore limbs is well shown in Fig. 727e. The Stegosaurians were, if pos-

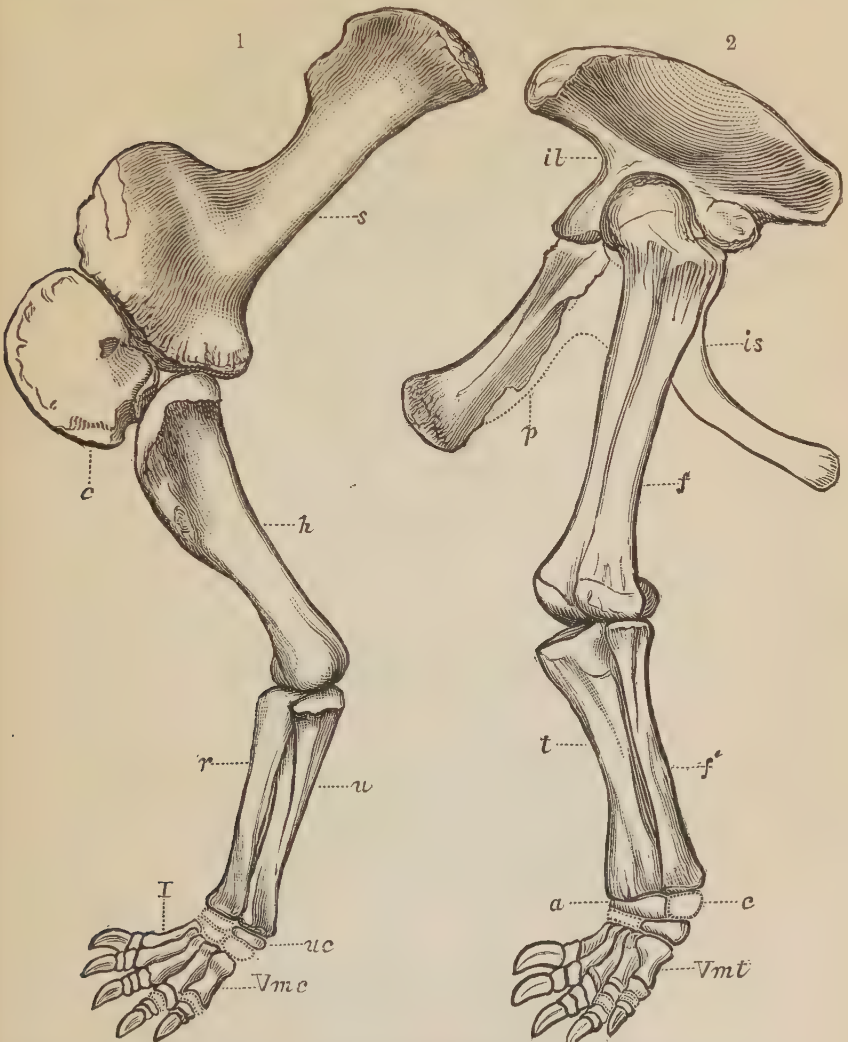


FIG. 727c.—1. Bones of left fore leg of Morosaurus grandis (after Marsh). One-twentieth natural size. *s*, scapula; *c*, coracoid; *h*, humerus; *r*, radius; *u*, ulna; *uc*, ulnar carpal; *I*, first metacarpal; *Vmc*, fifth metacarpal. 2. Bones of left hind leg of Morosaurus grandis, one-twentieth natural size. *il*, ilium; *is*, ischium; *p*, pubis; *f*, femur; *t*, tibia; *f'*, fibula; *a*, astragalus; *c*, calcaneum; *Vmt*, fifth metatarsal.

sible, still more remarkable. As their name implies, they were well protected with dermal plates and armed with dermal spines. The

plates have been found three feet in diameter, and the spines two feet long. The disparity between hind and fore limbs (Fig. 727g), greater than in any known Dinosaur, indicates that they habitually walked erect on their hind legs in the manner of birds. The brain

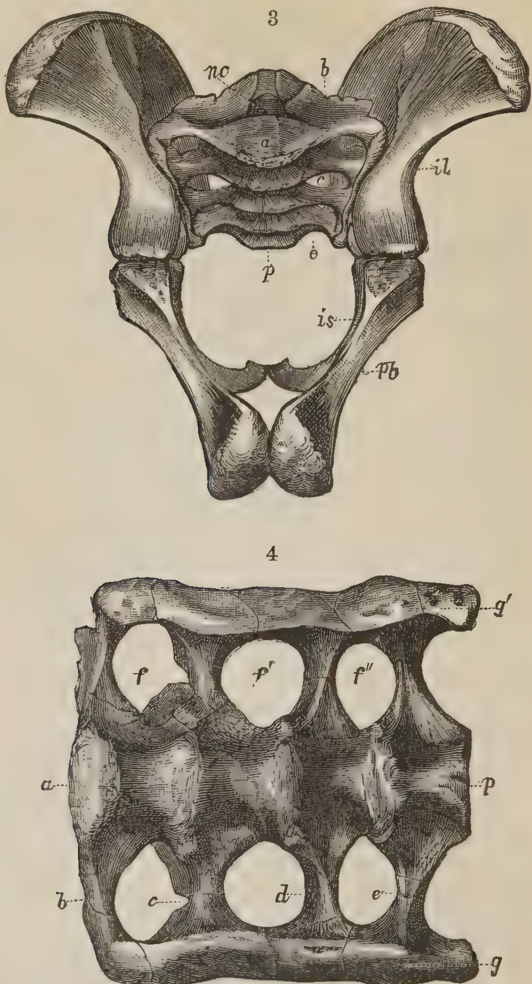


FIG. 727c.—3. Pelvic arch of Morosaurus grandis (after Marsh), seen from in front. One-sixteenth natural size. 4. Sacrum of Morosaurus grandis, seen from below. One-tenth natural size. *a*, first sacral vertebra; *b*, transverse process of first sacral vertebra; *c*, transverse process of second vertebra; *d*, transverse process of third vertebra; *e*, transverse process of last sacral vertebra; *f*, foramen between processes of first and second vertebra; *f′*, foramen between second and third processes; *f″*, foramen between third and last process; *g*, surface for union with right ilium; *g′*, same for left ilium; *p*, fourth, or last, sacral vertebra; *nc*, neural canal; *il*, ilium; *is*, ischium; *pb*, pubis.

of the Stegosaurus (Fig. 727h) was proportionally smaller than in any known reptile, but, as it were, to make up for this deficiency, the

spinal chord in the sacral region is enormously enlarged into a kind of posterior brain. The *sacral* brain (Fig. 727f) is at least ten times greater than the *cranial*. Some species of Stegosaurus attained a great size, not less than thirty feet in length.

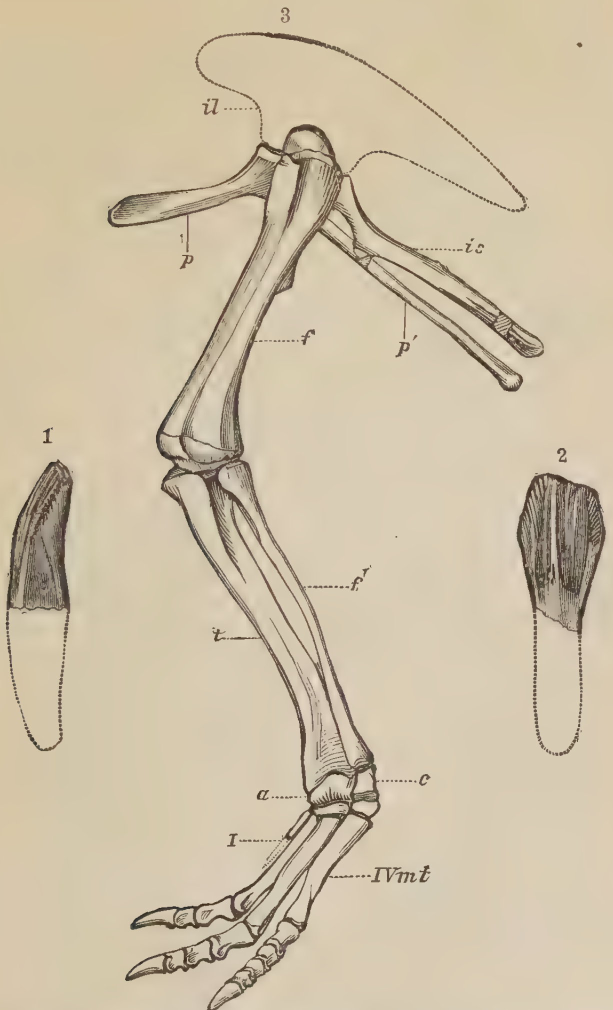


Fig. 727d.—1. Tooth of Laosaurus altus (after Marsh), front view. 2. The same, side view. Both twice natural size. 3. Bones of the left hind leg of Laosaurus altus (after Marsh). One-eighth natural size. *il*, ilium; *is*, ischium; *p*, pubis; *p′*, post-pubic bone; *f*, femur; *t*, tibia; *f′*, fibula; *a*, astragalus; *c*, calcaneum; *I*, first metatarsal; *IVmt*, fourth metatarsal.

Ichthyosaurs.—Besides the Dinosaurs, Marsh describes from the same formation (Jurassic), but from a lower horizon, an Ichthyosaurian, but differing entirely from the Ichthyosaurus of the European

Jurassic in being *toothless*. On this account he calls the genus *Baptanodon*. This reptile had six digits in both fore and hind feet, a new and most remarkable feature (see Fig. 727h).

Birds.—In 1881 Marsh discovered in the same beds, the Atlantosaur beds of Wyoming, a Jurassic bird, the only one yet known in

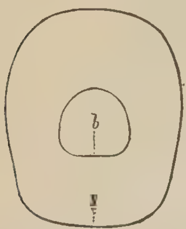
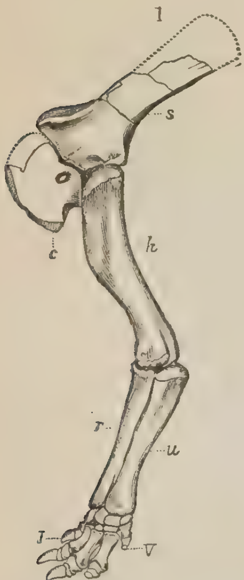


FIG. 727f.—Outlines representing transverse sections through brain of Stegosaurus ungulatus, and sacral cavity: *b*, brain; *s*, sacral cavity. One-fourth natural size (after Marsh).



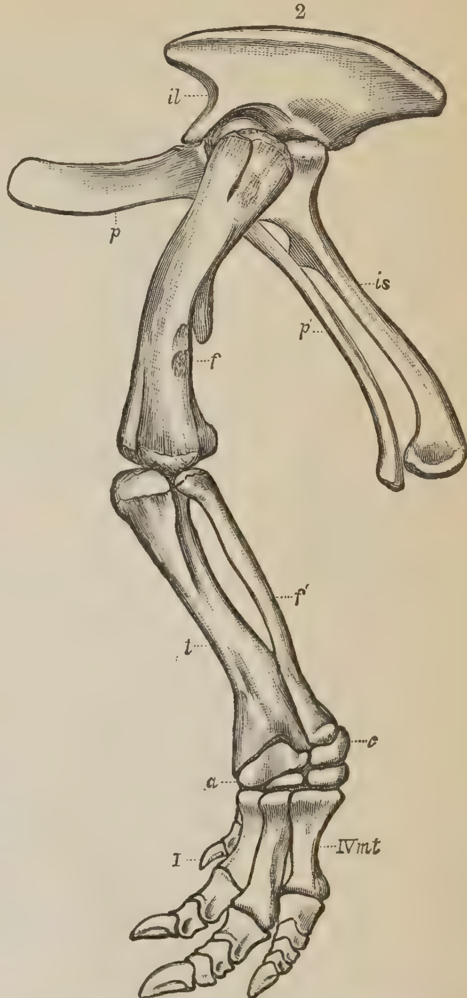


FIG. 727e.—1. Bones of left fore leg of Camptonotus dispar (after Marsh). *s*, scapula; *c*, coracoid; *h*, humerus; *r*, radius; *u*, ulna; *I*, first digit, *V*, fifth digit. 2. Bones of left hind leg of Camptonotus dispar. *il*, ilium; *is*, ischium; *p*, pubis; *p′*, post-pubis; *f*, femur; *t*, tibia; *f′*, fibula; *a*, astragalus; *c*, calcaneum; *I*, first metatarsal; *IVmt*, fourth metatarsal. Both figures one-twelfth natural size.

America. It was undoubtedly a reptilian bird (*Laopteryx*), probably with *teeth* and *bi-concave vertebræ;* but the remains are too imperfect to permit distinct characterization.

Mammals.—Lastly, in the same beds, Marsh has discovered some twenty species of small mammals. According to him, these earliest

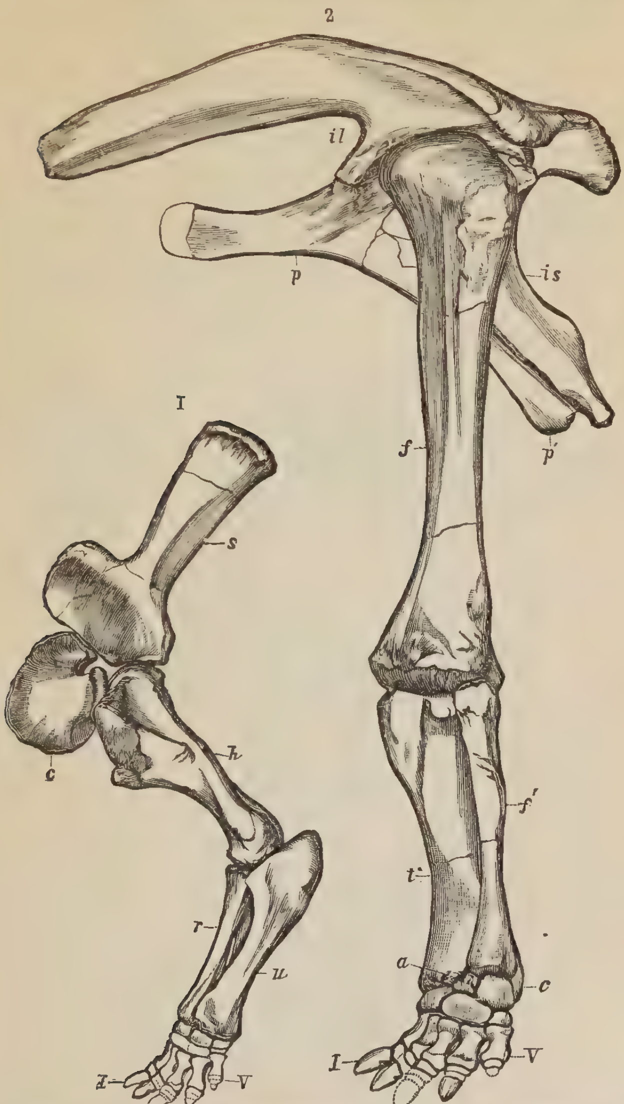


FIG. 727g.—1. Bones of left fore leg of Stegosaurus ungulatus (after Marsh): *s*, scapula; *c*, coracoid; *h*, humerus; *r*, radius; *u*, ulna; *I*, first digit; *V*, fifth digit. 2. Bones of left hind leg of Stegosaurus ungulatus: *il*, ilium; *is*, ischium; *p*, pubis; *p′*, post pubis; *f*, femur; *t*, tibia; *f′*, fibula; *a*, astragalus; *c*, calcaneum; *I*, first digit; *V*, fifth digit. One-sixteenth natural size.

mammals were not typical Marsupials, but a generalized type connecting that order with Insectivora. He makes of them two sub-orders,

Pantotheria and Allotheria. Figs. 727i and 727k are representatives of these two types.

Physical Geography of the American Continent during the Jura-Trias Period.—During Palæozoic times the Atlantic shore-line was

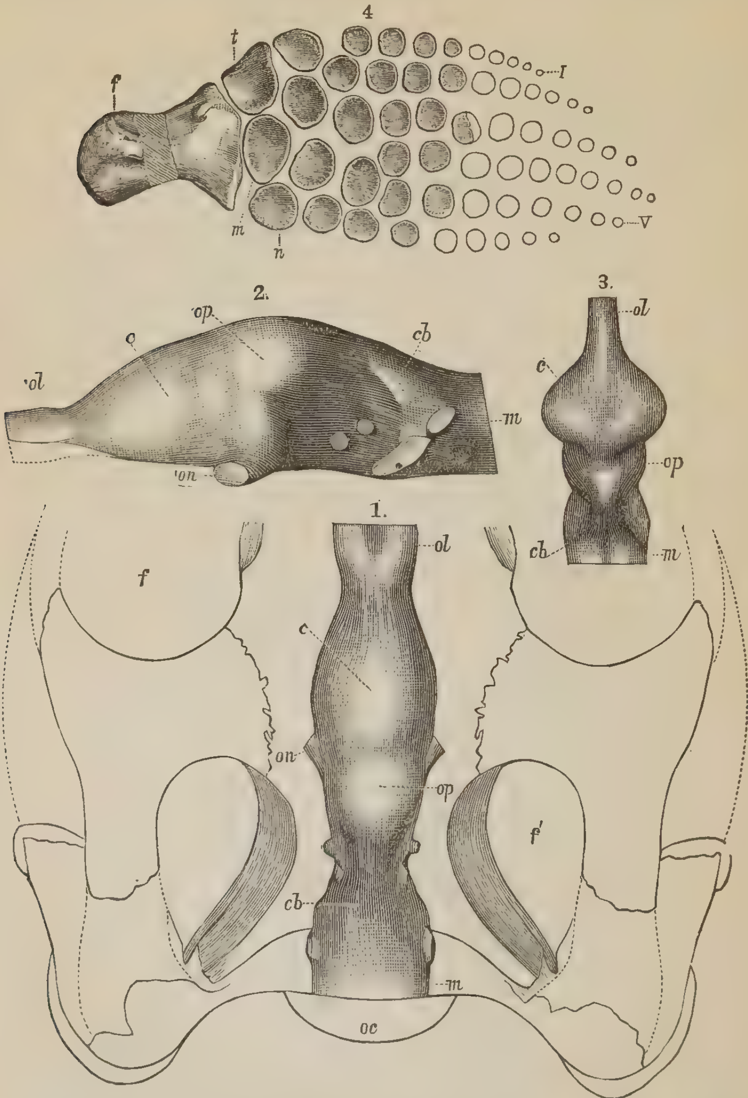


FIG. 727h.—1. Outline of skull and brain-cast of Stegosaurus ungulatus (after Marsh), seen from above. One-half natural size. *ol*, olfactory lobes; *c*, cerebral hemispheres; *op*, optic lobes; *on*, optic nerve; *cb*, cerebellum; *m*, medulla; *f*, orbital cavity; *f'*, temporal fossa; *oc*, occipital condyle. 2. Same brain-cast, side view. One-half natural size. 3. Brain-cast of young alligator. Three-fourths natural size. 4. Left hind paddle of Baptanodon discus (after Marsh), seen from below. One-eighth natural size. *f*, femur; *t*, tibia; *i*, intermedium; *f'*, fibula; *I*, first digit; *V*, fifth digit.

certainly farther east than it was *subsequently*, probably farther east than it is *now* (p. 266). At the end of the Palæozoic occurred the Appalachian revolution. Coincidently with the up-pushing of the Appa-

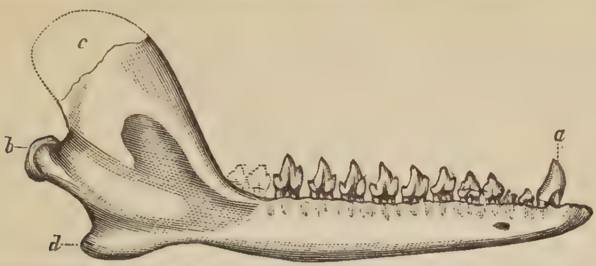


FIG. 727i.—Right lower jaw of Diplocynodon victor (after Marsh), outside view. Twice natural size. *a*, canine; *b*, condyle; *c*, coronoid process; *d*, angle.

lachian chain, the sea-border probably went downward, and the shore-line advanced westward on the land. During the Jura-Trias the shore-line to the north was still beyond what it is now, for no Atlantic border deposit is visible; and along the Middle and Southern States

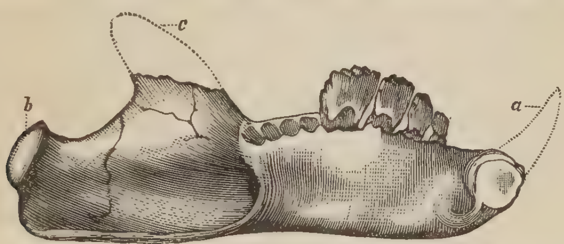


FIG. 727k.—Left lower jaw of Ctenacodon serratus (after Marsh), inner view. Four times natural size.

it was certainly beyond the bounding-line of Tertiary and Cretaceous (see map, p. 289), for all the Atlantic deposits of this age have been covered by subsequent strata; and yet, probably not much beyond, for some of these Jura-Trias patches seem to have been in tidal connection with the Atlantic Ocean. It is probable, therefore, that the shore-line was a little beyond the present New England shore-line, and a little beyond the old Tertiary shore-line of the Middle and Southern Atlantic States.

A little back from this shore-line, and at the foot of the then Appalachian chain, there was a series of old erosion or plication hollows stretching parallel to the chain. The northern ones had been brought down to the sea-level, and the tides regularly ebbed and flowed there then as in the bay of San Francisco, or Puget Sound, at the present time. In the waters of these bays lived swimming Reptiles, Crocodilian and Lacertian, and on their flat, muddy shores walked great bird-like Reptiles, and possibly reptilian Birds. The more southern

hollows seemed to have been above the sea-level, and were alternately coal-marsh and fresh-water lake, emptying by streams into the Atlantic; or, according to Russell, there may have been but one great sound stretching from Nova Scotia to North Carolina, in which the tides flowed and ebbed, the southern end being swampy or marshy. Since that time the coast has risen 200 or 300 feet, and these patches are therefore elevated so much above the sea-level.[1]

Meanwhile, somewhat similar changes were going on in the western portion of the continent. During Palæozoic times, the Pacific shore-line was just east of the Sierra range, and the place of this range was a marginal sea-bottom. At the end of the Palæozoic, coincidently with Appalachian revolution already explained (p. 412), the Utah Basin region was elevated and became land, while the Nevada Basin region subsided, and the Pacific shore-line advanced eastward to Battle Mountain.[2] But the whole area between this Basin region continent and the Palæozoic area of eastern North America, including the Plateau region and the Plains region, was covered by a shallow inland sea, with imperfect connection, or none at all, with the ocean, and in which, therefore, gypsum deposited by evaporation. At least once during Jurassic times this inland sea became broadly connected with the ocean, so that oceanic conditions prevailed. The place now occupied by the Wahsatch Mountains was *then a marginal sea-bottom*, bordering the Basin region continent. On the west the Pacific shore-line was some distance east of the Sierra, and the place of that range was still a sea-bottom, though not so closely marginal as in Palæozoic times.

Disturbances which closed the Period.—This long Jura-Trias period was closed, and the Cretaceous period inaugurated, by the *Sierra revolution*, by which the sediments accumulated along the then Pacific shore bottom, yielding to the lateral pressure, were mashed together and swollen up into the Sierra and Cascade ranges, and the coast-line transferred westward to the other side of these ranges. Coincidently with this change probably occurred on the Atlantic slope the elevation of the Jura-Trias sound and the outbursts of igneous matter, forming the trap-ridges already spoken of (p. 452). Extensive changes also occur at the same time over the whole region of the inland seas, by subsidence and the inauguration of oceanic conditions, which continued to prevail during the Cretaceous. There is reason to believe also that many of the Basin ranges were formed at this time (King). It was essentially a period of mountain-making in America.

Section 4.—Cretaceous Period.

The most general characteristic of this period is its transitional character. In it Mesozoic types are passing out, and Cenozoic or modern types are coming in, and the two types therefore coexist side

[1] See Appendix to p. 453. [2] See Appendix to p. 412.

by side. Nearly everywhere in America, as far as known, the Cretaceous lie unconformably on the Jurassic or still lower rocks.

Rock-System—Area in America.—On the *Atlantic border* going southward, we find no Cretaceous rocks until we reach New Jersey. Here we find a small patch peeping out from under the edge of the overlying Tertiary, and marked on the map (p. 289) by oblique interrupted lines. This patch passes through New Jersey, Delaware, Maryland, to the borders of Virginia. Passing south, we find no continuous area until we reach Georgia; yet it underlies the Tertiary in all this region, as is shown by the fact that the rivers in North and South Carolina cut through the Tertiary and expose the Cretaceous in many places. The *Gulf*-border Cretaceous commences in Western Middle Georgia, covers all the prairie region of Middle Alabama, the northeastern or prairie region of Mississippi, then runs northward as a narrow strip through Tennessee nearly to the mouth of the Ohio. It then disappears beneath the Tertiary to reappear as an area bordering the Gulf Tertiary on the west side. *On the interior plains*, the Cretaceous connecting with the Gulf-border area stretches northwestward to arctic regions, occupying nearly the whole of the great, grassy, level Western Plains called *Prairies*—though much of it is overlaid by the subsequent Tertiary. *In the Rocky Mountain* region Cretaceous strata occupy also large areas in all the Plateau region—i. e., the region between the Eastern range and the Wahsatch range—although here also it is largely overlaid by Tertiary. Recent investigations in Mexico[1] render it probable that this area stretches also westward through Northern Mexico to the Pacific. On the *Pacific border*, Cretaceous strata form a large part of the Coast ranges, and also in places the lowest western foot-hills of the Sierra range. Whitney has estimated the thickness of the Cretaceous rocks in portions of the Coast range as 20,000 feet.

Physical Geography in America.—It is not difficult from the Cretaceous area just given to reconstruct approximately the physical geography. At that time the *Atlantic shore-line* in all the *northern* portion of the continent was farther *out* or *east* than now, for the Cretaceous of this part is all now covered by sea. From New Jersey southward the shore-line was then farther *in* or *west* than now. From Maryland to Georgia the shore-line, though farther *in* than now, was farther *out* than during the Tertiary, as the Cretaceous is covered by the later deposits. *The Gulf shore-line* was much more extended both northward and westward than either now or in Tertiary times. From the Gulf there extended northwestward an immensely *wide sea*, covering the Plains region and the Rocky Mountain region as far westward as the Wahsatch range, and dividing the continent into two continents, an eastern or Appalachian, and a western or Basin region continent. Probably

[1] *American Journal of Science*, vol. x., p. 386, 1875.

also this sea connected across the region of Mexico with the Pacific, thus dividing the western continent into two, a northern and a southern. The Pacific Ocean at that time washed against the foot-hills of the Sierra range. These facts are represented in the accompanying map. The probable connection of the Gulf with the Pacific is also indicated.

FIG. 728.—Map of North America in Cretaceous Times.

Rocks.—The rocks of the Cretaceous period consist of sands, and clays, and limestones, as in other periods, but, as a whole, are less generally metamorphic than the older rocks. There is, however, one kind of rock found in this age in Europe which is so peculiar and so interesting that it must not be passed over in silence. We refer to the white *chalk* of England and France, from which the formation and the period take their name, " *Cretaceous*."

Chalk.—Chalk is a *soft*, *white*, *pure carbonate of lime*. Scattered through the soft mass are found very characteristic nodules of pure flint. These nodules are of various sizes and shapes, sometimes scattered *irregularly*, sometimes arranged in *layers*. Often some fossil, especially a sponge, forms the nucleus around which the aggregation of the siliceous matter takes place. On account of its extreme softness, chalk is often sculptured by erosive agencies into fantastic cliffs and needles (Fig. 729).

Examined with the microscope, chalk is found to be composed largely of Rhizopod shells, and of Coccoliths and Coccospheres (supposed shells of uni-celled plants), some perfect, more broken, most of all completely disintegrated (Fig. 730). The flint-nodules, similarly examined by sec-

tion, show spicules of sponge and siliceous shells of *Diatoms*. Chalk such as described is found nowhere except in Europe. Figs. 731–734 represent some of the more common Rhizopods found in chalk.

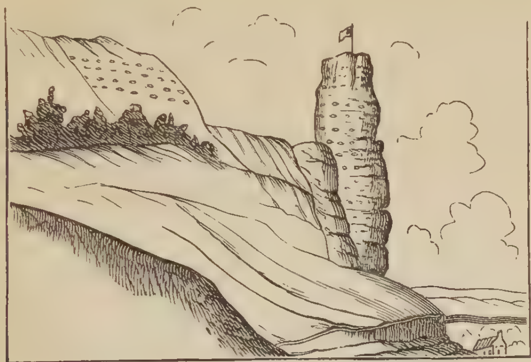


Fig. 729.—Chalk-Cliffs with Flint-Nodules.

Origin of Chalk.—A material so unique must have been formed under peculiar conditions. Recent investigations have shown that

Fig. 730.

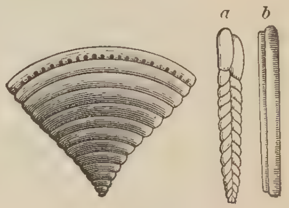


Fig. 731.

Fig. 732

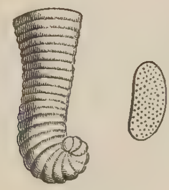


Fig. 733.

Fig. 734.

Figs. 730–734.—Foraminifera of Chalk: 730. Chalk as seen under the Microscope (after Nicholson). 731. Cuneolina pavonia. 732. Flabellina rugosa. 733. Lituola nautiloides. 734. Chrysalidina gradata (after D'Orbigny).

chalk is a *deep-sea ooze*. In all the deep-sea soundings and dredgings recently undertaken, it is found that the sea-bottom between the depths

of 3,000 and 20,000 feet, where not too cold, is a white ooze, consisting mainly of Rhizopod shells (Globigerina, Radiolaria, etc.) and Coccoliths, Coccospheres, etc., through which are scattered siliceous shells of Diatoms. These shells are in every stage of change: some living, or at least still retaining sarcode; some perfect, though dead and empty; some broken; most completely disintegrated into an impalpable mud. From the great abundance of one genus of Rhizopods, this calcareous mud has been called *Globigerina ooze.* In deep-sea bottoms, therefore, chalk is *now* forming. Also, strange to say, many Sponges, and Starfishes, and Echinoids, and Crustaceans, *very similar to those* formed in the chalk of Cretaceous times, have been brought up from present deep-sea bottoms.

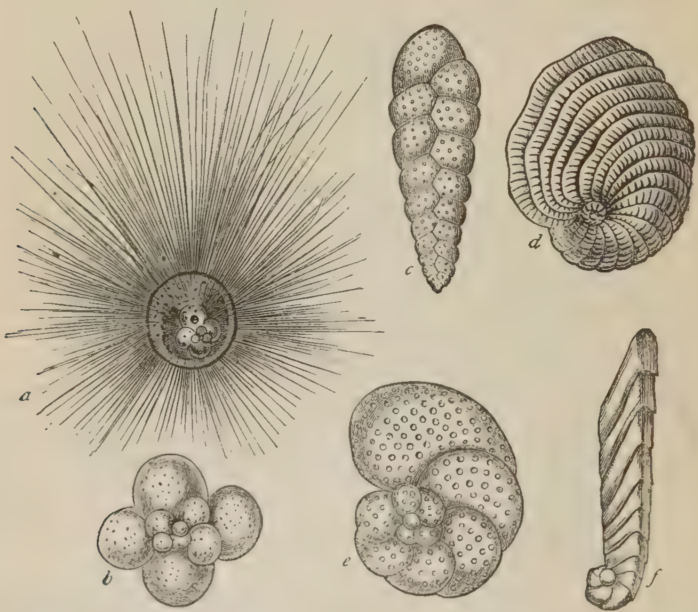


FIG. 735.—Shells of Living Foraminifera: *a*, Orbulina universa, in its perfect condition, showing the tubular spines which radiate from the surface of the shell; *b*, Globigerina bulloides, in its ordinary condition, the thin hollow spines which are attached to the shell when perfect having been broken off; *c*. Textularia variabilis; *d*. Peneroplis planatus; *e*, Rotalia concamerata; *f*, Cristellaria subarcuatula. (Fig. *a* is after Wyville Thomson; the others are after Williamson. All the figures are greatly enlarged.)

There seems little doubt, therefore, that chalk is a deep sea-bottom formation. The flint-nodules have been formed by a subsequent process similar to that which gives rise to other nodules (p. 188). The silica, which in the ooze was at first scattered, is slowly aggregated into pure flint-nodules, and the matrix is left in a condition of pure carbonate of lime.[1]

Extent of Chalk Seas of Cretaceous Times in Europe.—Chalk of

[1] Wallace thinks that chalk is a coral mud formed in warm seas full of foraminiferal life ("Island Life," p. 84).

nearly homogeneous aspect prevails from the north of Ireland through Middle Europe to the Crimea and Caucasus,[1] a distance of 1,140 miles; and, in the other direction, from the south of Sweden to the south of Bordeaux, a distance of 840 miles (Lyell). It is evident, therefore, that at that time a deep sea occupied a large portion of Central Europe. The white chalk of England and France is about 1,000 feet thick. When we remember the mode in which it has been formed, this thickness indicates an almost inconceivable lapse of time.

Cretaceous Coal.—Coal is again found in large quantities in rocks of this period in the United States. The mode of occurrence is similar to that found in rocks of other periods.

There has been, and still is, much difference of opinion and discussion among the best observers as to the exact position of the coal or lignites of the Pacific coast, of the Rocky Mountains, and of the Plains. Some have been referred to the Cretaceous, some to the Eocene, and some to the Miocene-Tertiary. With the exception of the last, however, most or perhaps all the productive fields seem to belong to nearly the same horizon, which has been called the *Great Lignitic formation*, or Laramie beds, and which by some geologists is regarded as uppermost Cretaceous, by others as lowermost Eocene. The animal fossils seem to ally the strata with the Cretaceous, the plants with the Eocene.[2]

The truth is, the Great Lignitic of the West seems to be a transition between the Cretaceous and the Eocene. While it was depositing, the changes of physical geography and climate which closed the Cretaceous and inaugurated the Tertiary had already been accomplished; but Cretaceous types still lingered, ready to disappear. The death-sentence had been pronounced, but the execution was delayed. In this group, therefore, Cretaceous and Tertiary forms are more or less mingled. This is precisely what we might expect; for in the drying up, by upheaval, of the Cretaceous interior sea, marine animals would be gradually changed into brackish-water and finally into Tertiary fresh-water animals; the *newly-formed* land would be covered with a Tertiary vegetation, but the Cretaceous land animals would still hold out for a while.

Since some of these fields are undoubtedly Cretaceous, it seems best, in order to avoid repetition, to speak of them all in this connection; but as the plants found are entirely different from the Cretaceous plants to be presently described, and wholly of Tertiary types, it seems best, until the question is settled, to speak of these under the Tertiary.

First, *on the Plains*, just east of the Rocky Mountains, there are several immense fields: one on the Upper Missouri and Yellowstone, another about Denver and Marshall, and still another farther south in

[1] Favre, "Archives des Sciences," vol. xxxvii., p. 118, *et seq.*

[2] This transition-formation is now most usually called "Laramie beds," or sometimes "Post-cretaceous."

New Mexico. These coal-fields are supposed to have an aggregate extent of at least 15,000 square miles. Beyond the limits of the United States, in the British possessions, are found still other fields (Dawson). Again, in the Plateau region, between the eastern Rocky Mountain range and the Wahsatch Mountains, on the Laramie Plains, is found a very fine field of 5,000 square miles. Again, on the Pacific slope are several important fields: 1. Monte Diablo and Corral Hollow coal-field, in California; 2. Seattle and Bellingham Bay coal-field, of Washington Territory; 3. The Nanaimo and Queen Charlotte's Island coal-field, of British Columbia.

We recapitulate the coal-fields of the United States, and present them at one view in the following table:

Carboniferous..	Appalachian.......	60,000	191,700 square miles.
	Central...........	47,000	
	Western..........	78,000	
	Michigan..........	6,700	
Jura-Trias.....	Richmond.. / Piedmont..	170	670 square miles.
	Deep River. / Dan River..	500	
Cretaceous.....	Western Plains... / Rocky Mountains.	20,000—	20,000 square miles.
	Monte Diablo, etc. / Washington......	unknown.	
	Total..................		212,370 square miles.

Of which at least 150,000 square miles are workable.

The Cretaceous coals are usually called *lignites*, but they are really a very fair coal, and quite different from what usually goes under that name.

Subdivisions of the Cretaceous.—The Cretaceous in America is divided into upper and lower; in Europe it is divided into upper, middle, and lower, the chalk being the upper. The following table shows the relation of western American to English Cretaceous:

		AMERICAN.	ENGLISH.	
LOWER TERTIARY.		WAHSATCH BEDS.	PLASTIC CLAY.	
Laramie beds, or Transition.		Fort Union. Judith River. Butter Creek.	Wanting.	
Cretaceous.......	Upper.	Fox Hill. Fort Pierre.	White chalk.	Upper.
	Lower.	Niobrara. Fort Benton.	Gray chalk.	
		Dakota.	Upper Greensand.	Middle.
		Wanting.	Lower Greensand.	Lower.
UPPER JURASSIC.		ATLANTOSAUR BEDS.	WEALDEN.	

It is probable that the lowermost Cretaceous of Europe is unrepresented in the United States, except on the Pacific coast, where it is probably represented by the *Shasta group* of California and Queen Charlotte's Island, British Columbia (Newberry). If so, the reason is evident. The Sierra revolution was a great event. A gap in the record is the result. Some of the leaves missing here are recovered in Europe.

Life-System: Plants.

Leaf-impressions are very abundant in the American Cretaceous, and the most cursory examination reveals at once a type of plants not seen in any lower rocks, viz., *Angiosperms*, both Dicotyls and Palms. We have said that the Sierra revolution at the end of the Jura-Trias pro-

Fig. 736.

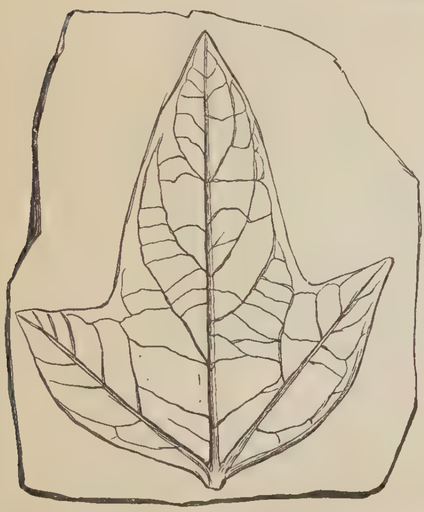


Fig. 737.

Fig. 738.

Fig. 739.

Figs. 736-739.—Cretaceous Plants (after Lesquereux): 736. Liquidambar integrifolium. 737. Sassafras Mudgei. 738. Laurus Nebrascensis. 739. Quercus primordialis. All reduced.

duced great change in America. It is probable that a break occurs in the record here. When the record commences again with the Creta-

ceous, we observe a very great difference in the subject matter. The whole aspect of field and forest must have been different and much more modern. Nearly all the genera of our modern trees are present, e. g., *Oaks*, *Maples*, *Willows*, *Sassafras*, *Dogwood*, *Hickory*, *Beech*, *Poplar*,

FIG. 740.

FIG. 741.

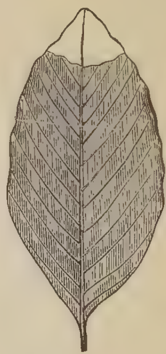


FIG. 742.

FIG. 743.

FIGS. 740–743.—CRETACEOUS PLANTS (after Lesquereux): 740. Sassafras araliopsis. 741. Salix proteæfolia. 742. Fagus polyclada. 743. Protophyllum quadratum. All reduced.

Tulip-tree (Liriodendron), *Walnut*, *Sycamore*, *Sweet-gum* (Liquidamber), *Laurel*, *Myrtle*, *Fig*, etc. Out of 130 species of plants found in the Cretaceous of Nebraska, about 110 species are Dicotyls, and at least half of these belong to *living* genera (Lesquereux). And if we include

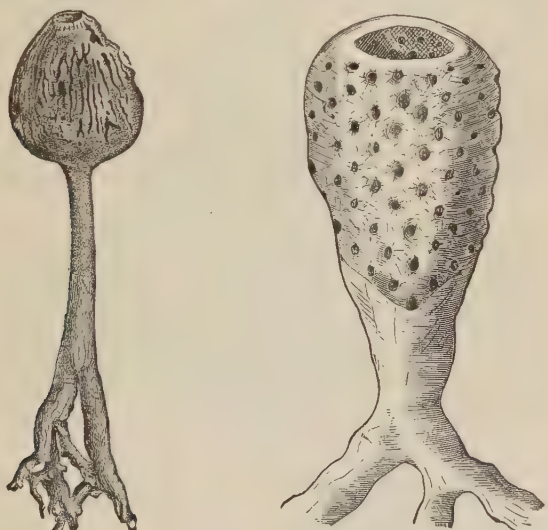
the Lignitic in the Cretaceous we may add 200 more species to the list, but these latter are quite different and Tertiary in type. A few Palms have also been found in Vancouver's Island.

It is a noteworthy fact that many of the most characteristic Cretaceous genera, and those most abundant and varied in species at that time, are now represented by only one or two species. For example, there are now only two species of Sassafras; one species of Plane-tree; one of Liriodendron; and one of Liquidamber. These are evidently the remnants of an extinct flora.

But if the highest plants, the Dicotyls, are abundant, so are also the lowest *Protophytes* or uni-celled plants. Diatoms, Desmids, Coccospheres, are abundant in the chalk of Europe. If they are not found in America, it is only because deep-sea deposits have not yet been found there.

Animals.

Protozoa.—As already stated, chalk is made up almost wholly of shells of Foraminiferæ (Rhizopods) and of certain uni-celled plants. According to Ehrenberg, a cubic inch often contains millions of microscopic organisms. More than 120 species of Foraminifers have been



FIGS. 744, 745.—CRETACEOUS SPONGES: 744. Siphonia ficus. 745. Ventriculites simplex.

found in the English chalk alone. Some of these seem to be species *still living* in deep seas. These are all extremely minute, but some of larger size are found in the Cretaceous limestone of Texas. Those from the chalk have already been given.

Sponges are extremely common in the chalk, as they are also in

deep-sea bottoms of the present day. About one hundred have been found in the chalk.

Echinoderms.—The free Echinoderms are now for the first time in excess of the stemmed. Only very recently, the first *Crinoid* yet found in the American Cretaceous has been obtained by Marsh, and described by Grinnell. The *Uintacrinus socialis* (Fig. 746) was a free Crinoid like the Marsupites of the English chalk, or the Comatula of the present seas. They seemed to have lived together in great numbers in Cretaceous times in the region of the Uintah Mountains, then a Cretaceous sea. Fig. 746 represents the body; the arms were exceedingly numerous and complex. The *Echinoids* are especially abundant and decidedly

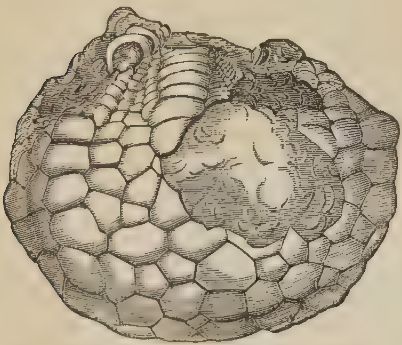


Fig. 746.—Uintacrinus socialis (after Grinnell).

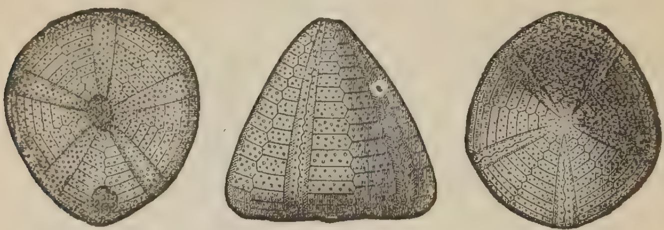


Fig. 747.

Fig. 748.

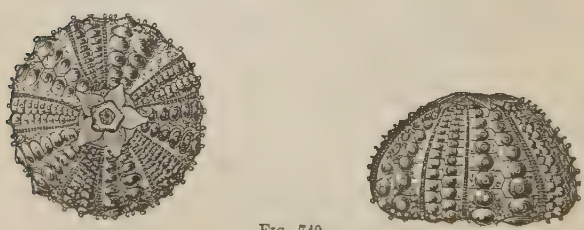


Fig. 749.

Figs. 747-749.—Echinoids of the Cretaceous of Europe: 747. Galerites albogalerus. 748. Discoidea cylindrica. 749. Goniopygus major.

modern in type; and in the chalk some genera are identical with, and some species very similar to, those recently gotten from *deep-sea ooze.* The above are from the European Cretaceous.

Fig. 750.

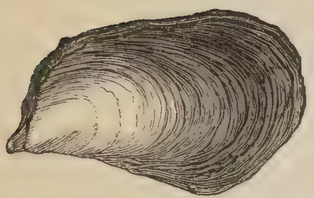


Fig. 751.

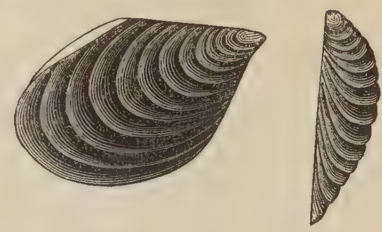


Fig. 752.

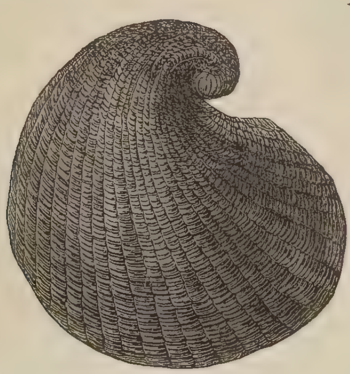


Fig. 753.

Figs. 750–753.—Cretaceous Brachiopods and Lamellibranchs—*Brachiopods:* 750. Terebratula Astieriana.—*Lamellibranchs:* 751. Ostrea Idriaensis (after Gabb). 752. Inoceramus dimidius (after Meek). 753. Exogyra costata (after Owen).

Mollusks.—For the first time *Lamellibranchs* are fairly in excess of *Brachiopods.* Among the latter the modern family of Terebratulæ are especially conspicuous (Fig. 750). Among the former the most noteworthy fact is the abundance of the Oyster family—*Ostrea*, *Gryphœa*, *Exogyra*, etc.; and the Avicula family, *Avicula*, *Inoceramus*, etc., some of which are of great size.

Another very strange and characteristic group of shells found here are the *Rudistes* or *Hippuritidæ.* In this family one valve is comparatively small, and often flat, while the other is enormously deep and elongated in the shape of a cow's-horn in Hippurites and Radiolites (Fig. 754), or in the shape of a closely-coiled ram's-horn in Caprinella and Caprina (Fig. 757). The figures are taken from foreign localities, but similar forms exist also in this country.

Fig. 754.

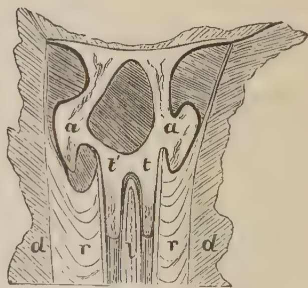


Fig. 755

Fig. 756.

Fig. 757.

Figs. 754–757.—754. Hippurites Toucasiana, a large individual with two small ones attached (after d'Orbigny). 755. Section of a Radiolites cylindriasus, showing structure. 756. Upper Valve of Radiolites mammelaris. 757. Caprina adversa (after Woodward).

Among *Gasteropods*, the beaked or siphonated kinds are now for the first time abundant, as in the present seas (Figs. 758–760).

Among *Cephalopods* the *Ammonites* and *Belemnites* still continue in great numbers and size, but they die out at the end of this period forever. In the Cretaceous of the Western Plains some Ammonites have

been found over three feet in diameter (Dana). This family seemed to have reached its culmination just before its extinction. But what is still more remarkable is the introduction of many new genera of very strange and unexpected forms. These are sometimes *partly* uncoiled,

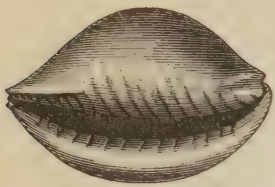


Fig. 758.

Fig. 760.

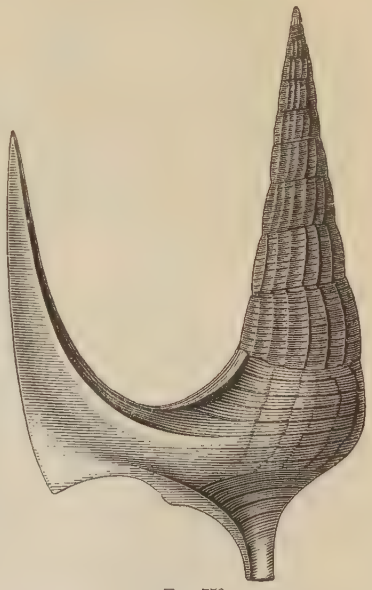


Fig. 759.

Figs. 758–760.—Cretaceous Gasteropods: 758. Cypræa Matthewsonii (after Gabb). 759. Aporrhais falciformis (after Gabb). 760. Scalaria Sillimani (after Lesquereux).

as in *Scaphites* (boat), *Crioceras* (ram's-horn), *Toxoceras* (bow-horn), *Ancyloceras* (hook-horn), *Hamites* (hook); sometimes completely uncoiled, as in *Baculites* (walking-stick); sometimes coiled spirally, like a Gasteropod, as in *Turrulites* and *Helioceras.* Belemnites also continue, though in diminishing numbers.

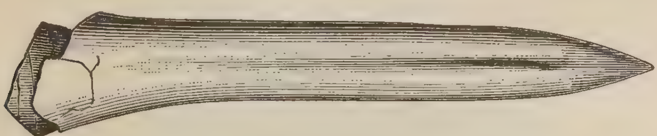


Fig. 761.—Belemnites impressus (after Gabb).

These strange forms have been likened by Agassiz to death-contortions of the Ammonite family; and such they really seem to be. From the point of view of evolution, it is natural to suppose that under the gradually-changing conditions which evidently prevailed in Cretaceous times, this vigorous Mesozoic type would be compelled to assume a

great variety of forms, in the vain attempt to adapt itself to the new environment, and thus to escape its inevitable destiny. The curve of its


FIG. 762.

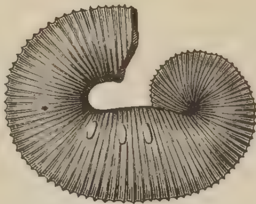


FIG. 763.

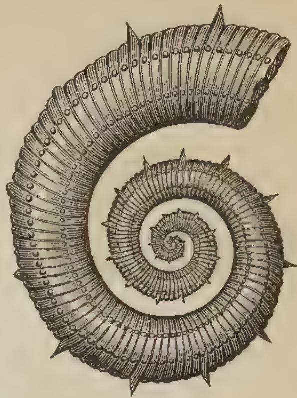


FIG. 764.

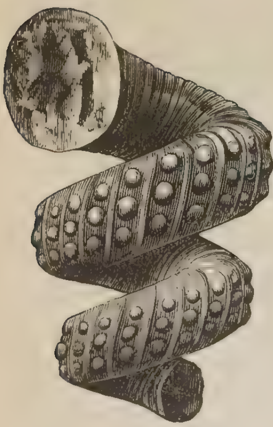


FIG. 765.

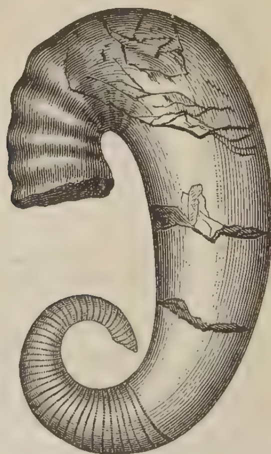


FIG. 766.

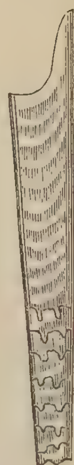


FIG. 767.

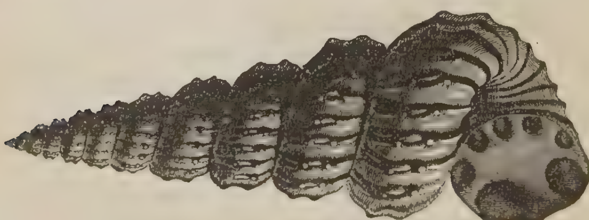


FIG. 768.

FIGS. 762–768.—CRETACEOUS CEPHALOPODS: 762. Ammonites Chicoensis (after Gabb). 763. Scaphites æqualis (after Pictet). 764. Crioceras, restored (after Pictet). 765. Helioceras Robertianus (after Pictet). 766 Ancyloceras percostatus, × $\frac{1}{8}$ (after Gabb). 767. Baculites anceps, × $\frac{1}{3}$ (after Woodward). 768. Turrulites catenatus (after D'Orbigny).

rise, culmination, and decline, reached its highest point just before it was destroyed. The wave of its evolution crested and broke into strange forms at the moment of its dissolution.

Among *Crustaceans*, the Brachyurans, short-tailed Crustaceans (crabs), which were barely introduced in the Jurassic, are here represented by several genera.

Vertebrates—Fishes.—In the development of this class some decided steps in advance are here recorded. Placoids and Ganoids still con-

Fig. 769.

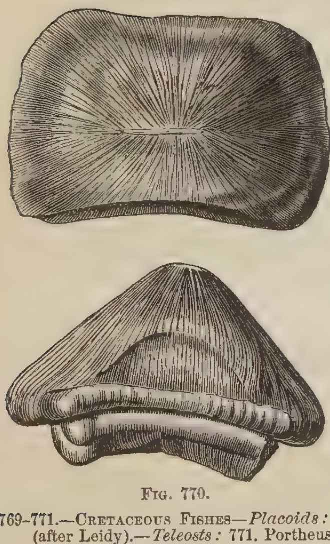


Fig. 770.

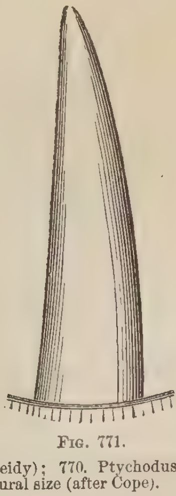


Fig. 771.

Figs. 769-771.—Cretaceous Fishes—*Placoids:* 769. Otodus (after Leidy); 770. Ptychodus Mortoni (after Leidy).—*Teleosts:* 771. Portheus molossus—Tooth, natural size (after Cope).

tinue, but *Teleosts*, or true typical modern fishes, are here introduced for the *first* time, and in considerable numbers, and some of gigantic

size. These earliest Teleosts were related to salmon, herring, perch, pike, etc. Beryx, a genus still found in open seas, is found in the Chalk of Europe and Upper Cretaceous of America. Among *Placoids*, too, although the Cestracionts and Hybodonts continue (the latter, however, passing out with the Cretaceous), the modern type, the true sharks or

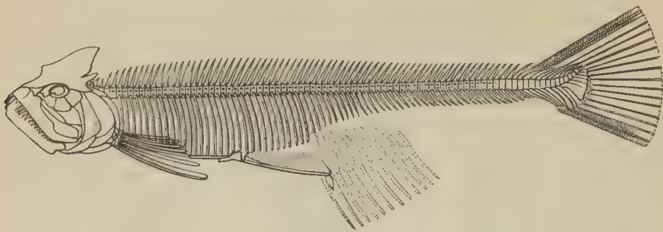


Fig. 772.

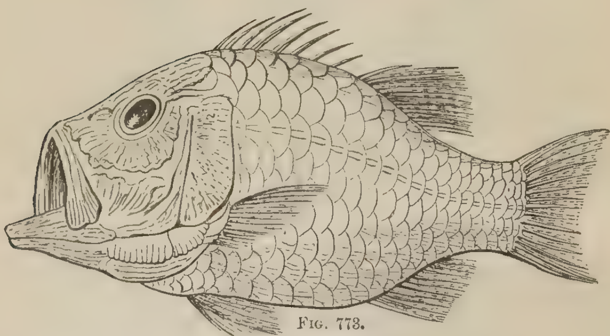


Fig. 773.

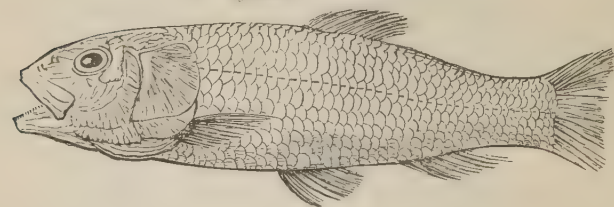


Fig. 774.

Figs. 772-774.—Cretaceous Fishes—*Teleosts:* 772. Portheus, restored, × $\frac{1}{28}$ (after Cope). 773. Beryx Lewesiensis. 774. Osmeroides Mantelli.

Squalodonts, having lancet-shaped teeth, are for the first time abundant. Above we give figures of Cestraciont and Squalodont teeth, and also a tooth, natural size, of a gigantic pike, eight feet long, from American Cretaceous, and a restoration of the same by Cope; also, two Teleosts from European Cretaceous.

The *Hybodonts* were essentially a *Mesozoic* type; the Squalodonts are essentially Tertiary and modern. The two types coexist in the Cre-

taceous, the former passing out, the latter increasing, and finally displacing the former.

Cope gives ninety-seven species of North American Cretaceous fishes known in 1875. Of these, if we include the Chimera family, an aberrant type of Placoids very common in the Cretaceous, *forty-five were Placoids.* The rest are mostly Teleosts, for the Ganoids are rapidly disappearing. In Europe, twenty-five genera of Cycloids and fifteen of Ctenoids are found in the Cretaceous (Dana).

Reptiles.—This class seems to have culminated about the end of the Jurassic or the beginning of the Cretaceous period. If their remains are more abundant in the Jurassic in Europe, they are far more abundant in the Cretaceous in America. In fact, we had here in America during that time an extraordinary abundance and variety of reptilian life, including all the principal orders already mentioned, viz., *Enaliosaurs*, *Dinosaurs*, *Pterosaurs*, and *Crocodilians*, and also a new type, introduced in the Cretaceous for the first time, the *Mosasaurs*, wholly marine in habits, but of long, slender, snake-like form, and attaining the greatest length yet known among reptiles. Turtles were also found in large numbers and of great size. We can mention only a very few of the most remarkable of the Cretaceous reptiles.

Among *Enaliosaurs* Leidy describes one *Discosaur* (Elasmosaur, Cope) allied to the Plesiosaur, which was fifty feet long, with a neck of

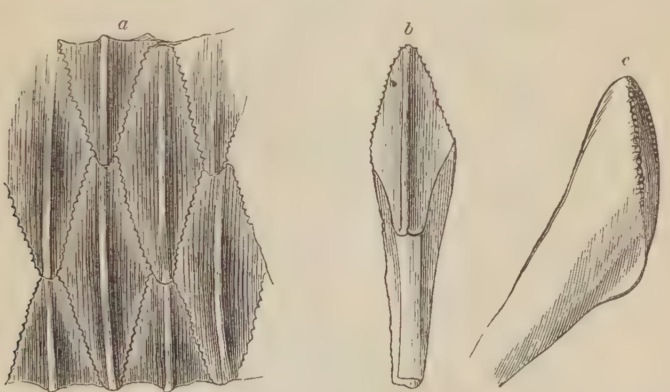


FIG. 775.—Teeth of Hadrosaurus (after Leidy): *a*, Pavement of Teeth; *b* and *c*, Tooth separated.

sixty vertebræ and twenty-two feet long. Among *Dinosaurs* the *Hadrosaur* from New Jersey was twenty-eight feet long; and, judging from the huge size of its hind-legs and massiveness of its hips and small size of its fore-legs, it seems to have been able to stand and walk in the manner of birds (Fig. 776). This animal was a vegetable-feeder, with teeth somewhat like those of the Iguanodon, but set in several rows, so as to form a kind of tessellated pavement (Fig. 775). From the same

locality the *Dryptosaurus* (*Lælaps*), similar to the Megalosaur, and twenty-four feet long, and the *Ornithotarsus* (bird-shank), thirty-five feet long, stood twelve to fifteen feet high when walking on their hind-legs.[1] Among *Pterosaurs*, Marsh has found in the Western Cretaceous the remains of at least six species, two of which were twenty to twenty-five feet in alar extent, and another eighteen feet.

Fig. 777.—Edestosaurus (Clidastes), restored by Cope.

The American Pterosaurs differ from all other known Pterosaurs in the fact, recently brought to light by Marsh, that their jaws were entirely *toothless*, and probably *sheathed with horn*, as in birds. They have therefore been placed by Marsh in a distinct order, *Pteranodontia*, from the type genus *Pteranodon* (winged-toothless). Probably all the American Pterosaurs belong to this order. One of them, *P. ingens*, had toothless jaws four feet long, and an expanse of wing of twenty-two feet.

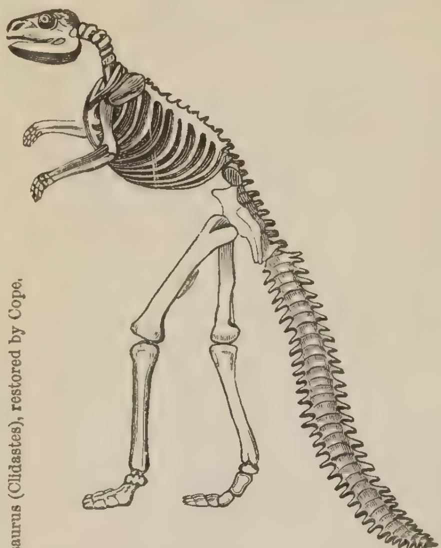


Fig. 776.—Hadrosaurus (restored by Hawkins).

Among the many *Chelonians* (turtles) found in the Cretaceous of the Western Plains, of the Rocky Mountain region, and of New Jersey, one, the *Atlantochelys gigas*, had a length of nearly thirteen feet, and a breadth across the extended flippers of fifteen feet (Cope). The structure of this huge turtle was singularly *embryonic*. The flattened ribs, which by their coalescence make the greater part of the shell of a turtle, were in this species, as in the embryo of modern turtles, *not yet coalesced*.

But the most remarkable and characteristic reptiles found in the Cretaceous are the *Mosasaurs* (*Pythonomorpha* of Cope). The first specimen of the order was found in Europe, on the river Meuse, and hence the name Mosasaurs; but they seem to have been far more abundant in America. At least fifty species (Cope) have

FIG. 778.

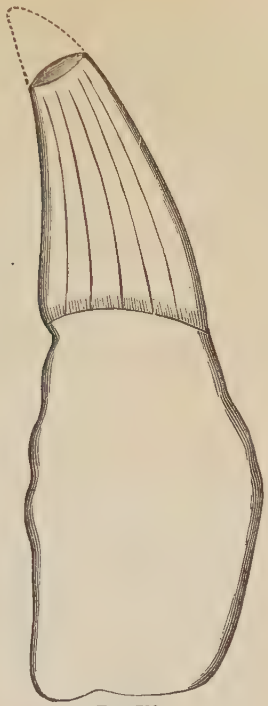


FIG. 780.

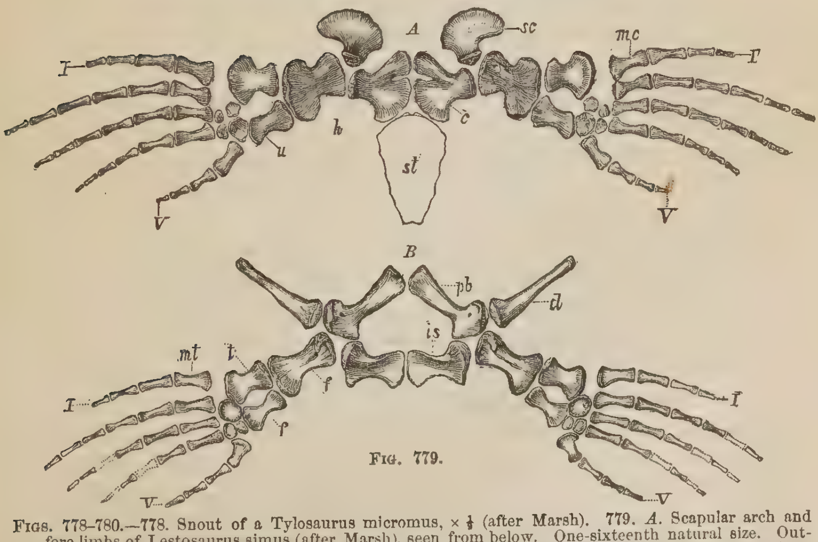


FIG. 779.

FIGS. 778–780.—778. Snout of a Tylosaurus micromus, $\times \frac{1}{3}$ (after Marsh). 779. *A*. Scapular arch and fore limbs of Lestosaurus simus (after Marsh), seen from below. One-sixteenth natural size. Outline of sterum from Edestosaurus. *B*. Pelvic arch and hind limbs of Lestosaurus simus, seen from below. One-twelfth natural size. *il*, ilium; *pb*, pubis; *is*, ischium; *f*, femur; *t*, tibia; *f'*, fibula; *mt*, metatarsal. The paddles are represented as horizontal, and the bones of the arches are somewhat displaced to bring them into the same plane. 780. Tooth of a Mosasaurus, $\times \frac{1}{2}$ (after Leidy).

been found in the Cretaceous of New Jersey, the Gulf States, and Kansas. Of these, the *Mosasaurus princeps* was sixty to seventy feet long, and *Tylosaurus* (*Liodon*) *dyspelor* probably "attained a length equal to the longest whale" (Cope). These reptiles seem to have united the long, slender form of a snake, and the short, strong, well-fingered paddles of a whale, with the essential characters of a lizard. Another snake-like character possessed by this order was rows of teeth on the palatal bones, in addition to those in the jaws; and a peculiar loose and movable articulation of the lower jaws, by

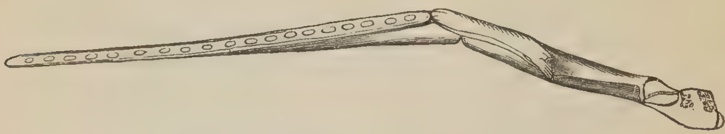


FIG. 781.—Jaw of an Edestosaurus (Clidastes), × ½ (after Cope).

means of which, when aided by the recurved teeth, the jaws could act separately like arms, in dragging down their throats prey which was too large to swallow directly (Fig. 781).

We give on page 488 a restoration by Cope of one of the most slender forms—Edestosaurus—and also, on page 489, head and tooth, and limbs, of other Mosasaurs.

The number of species are yearly increasing by new discoveries. The remains of at least fourteen hundred individuals of Mosasauroids are now alone gathered in Marsh's collection.

According to Cope, 147 species of reptiles have been described from the Cretaceous of North America, of which fifty are Mosasaurs, forty-eight Testudinata (turtles and tortoises), eighteen Dinosaurs, fourteen Crocodilians, thirteen Sauropterygia (Plesiosaur-like), and four Pterosaurs. At least three more Pterosaurs have been found, making the whole number seven (Marsh).

In Europe, Iguanodons, Teleosaurs, Ichthyosaurs, Plesiosaurs, and Pterosaurs still remain, some of the last being twenty-five feet in expanse of wing; and also a few Mosasaurs were introduced.

Birds.—The history of the discovery of the earlier fossil birds is instructive. Until 1858, with the exception of the doubtful tracks in the Connecticut River sandstone, no birds had been found lower than the Tertiary. In that year the bones of a bird, probably related to the gull, were found in the upper greensand of England. In 1862 the wonderful reptilian bird *Archæopteryx macroura*, already described (p. 448), was found in the Solenhofen limestone of Germany (Upper Jurassic). In 1870 and 1871 Marsh discovered in the Cretaceous of New Jersey and Kansas twenty species of birds: five Grallatores

(waders), like the Rail, Snipe, etc.; five Natatores (swimmers), allied to Cormorants, Divers, etc.; and ten wonderful *Toothed birds*, entirely different from any existing order. These were the most extraordinary birds which have ever been discovered. Some of them, belonging to the two genera *Ichthyornis* and *Apatornis*, were *without* the horny

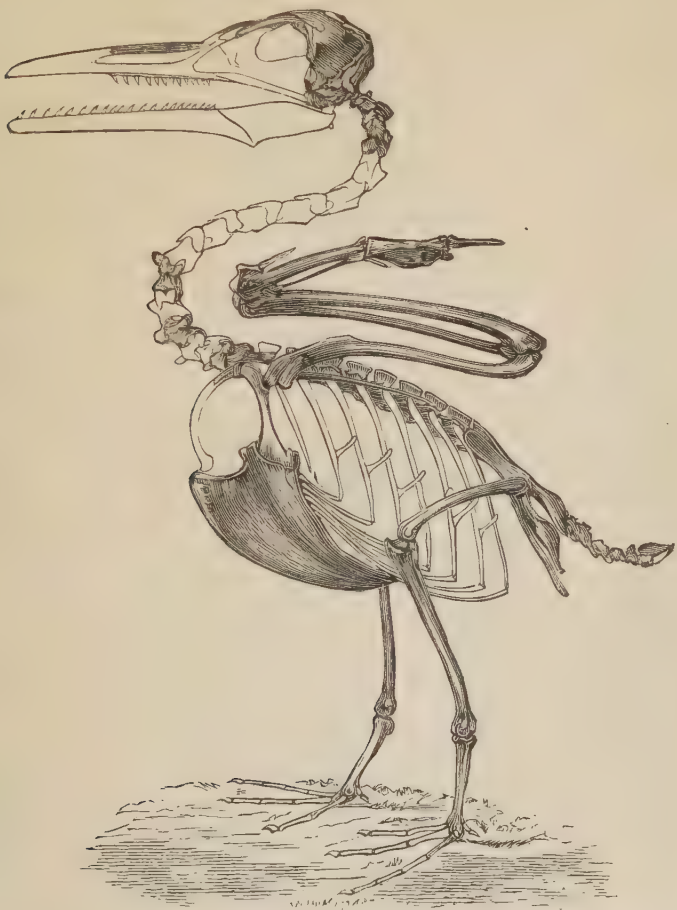


FIG. 781a.—Restoration of Ichthyornis victor (after Marsh). One-half natural size.

beak so characteristic of existing birds, but instead had *thin, long, slender jaws, furnished with many sharp, conical teeth, set in sockets*, twenty on each side below, and somewhat fewer above (Fig. 782). Their vertebræ were amphicœlous or bi-concave, as in fishes and many

extinct reptiles, but in no modern bird (Fig. 783). Like modern birds, however, they had a keel on the breast-bone for the attachment of the powerful muscles of flight. The tail also is worthy of atten-

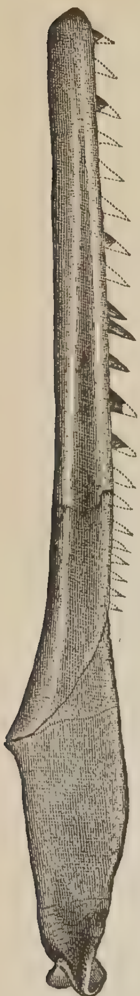


Fig. 782.

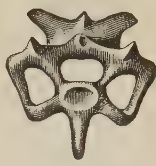


Fig. 783.

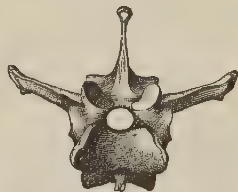


Fig. 785.

Fig. 786.

Fig. 784.

Figs. 782–786.—Odontornithes (after Marsh): 782. Lower Jaw of Ichthyornis dispar, × 2. 783. Cervical Vertebra of same, × 2. 784. Lower Jaw of Hesperornis regalis, × ½. 785. Dorsal Vertebra, × ½. 786. Tooth of same, × 2.

tion, being not like that of the Jurassic Archæopteryx, but much shorter and not so reptilian (Marsh). These birds were about the size of a pigeon, and were evidently powerful flyers. Fig. 781a

is a restoration by Marsh of one of this type. The other toothed birds had similar jaws, but their teeth were set in grooves instead of distinct sockets (Fig. 784), and they differed also in having no keel and in having ordinary bird-vertebræ (Fig. 785). These were evidently divers, and *incapable of flight.* Two of them—*Hesperornis regalis* and *Lestornis crassipes*—were of gigantic size, being from five to six feet from snout to toe. Below (Fig. 787) we give a restoration by Marsh of this remarkable bird. In these birds, therefore, we have the most extraordinary combination of bird characters with reptilian and fish characters. So extraordinary and exceptional is this combina-

Fig. 787.—Hesperornis regalis (restored by Marsh).

tion of characters, that Marsh believes he is justified in placing them not only in new orders, but even in a new sub-class. According to this authority, the class of Birds may be divided into two sub-classes, viz., *Ornithes,* or true birds, and *Odontornithes,* or *toothed* birds. And the new sub-class Odontornithes into three orders, viz. : (1) *Saururæ* (*reptile-tailed*), represented by the Archæopteryx, (2) *Odontolcæ* (teeth in grooves), represented by the Hesperornis, and (3) *Odontotormæ*

(teeth in sockets), represented by the Ichthyornis. Yet, exceptional as these characters may seem, they are just what the law of evolution would lead us to expect in the earliest birds. As already stated (p. 451), this branch had not yet been fairly separated from the reptilian stem. It is a noteworthy fact that these toothed birds lived at the same time and in the same localities with the toothless Pterosaurs mentioned on page 488.

It is a remarkable fact that in the earliest representations of each class the brain is relatively very small. This is true of reptiles, birds, and mammals. We give below figures taken from Marsh, showing the relative size of living and Cretaceous birds.

Mammals.—It is a most remarkable fact that although Marsupial mammals have been found in the Jurassic, and probably existed in considerable numbers then, yet not one has been found in the Cretaceous.

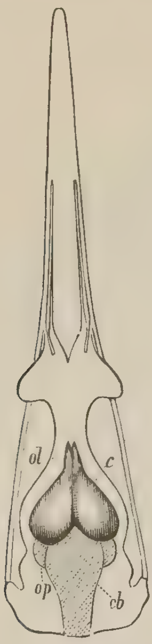


Fig. 787a.

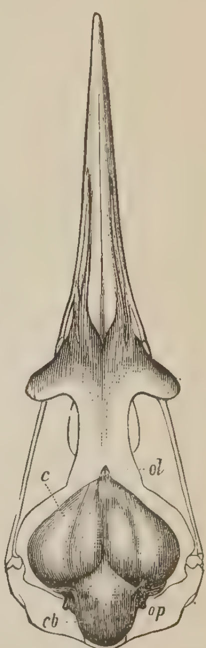


Fig. 787b.

Figs. 787a, 787b.—787a. Outline of the skull and brain-cavity of Ichthyornis victor (after Marsh), seen from above. Five-sixths natural size. 787b. Outline of the skull and brain-cavity of Sterna cantiaca (after Gmelin), same view. Natural size. *ol*, olfactory lobes; *c*, cerebral hemispheres; *op*, optic lobes; *cb*, cerebellum.

We know they existed at that time, for they are found in the Tertiary of both Europe and America, and *still* exist in Australia and elsewhere; and it is a well-established law in Paleontology that if a type becomes

extinct *it never reappears:* Evolution never goes backward: Nature never repeats herself. It is probable, therefore, that during the Cretaceous the Marsupials which doubtless existed had been driven to some other portion of the earth, where we shall yet find their remains when our knowledge of the geology of the globe is more complete; and in them we shall also probably find the transitions to, or earliest progenitors of, the True mammals of the Tertiary.

Continuity of the Chalk.

It is probable that the deep Atlantic Ocean bottom, where chalk is now forming, is continuous with the chalk of England and Central Europe. In other words, in Cretaceous times a deep sea ran from the mid-Atlantic far into what is now Central Europe, and in the whole of this deep sea chalk was then formed. At the end of the Cretaceous period the eastern part was raised and formed a portion of Europe, while the rest remained as deep-sea bottom, and continued to make chalk until now. Thus there is no doubt that in the deep Atlantic, off the coast of Europe, there has been *an unbroken continuity of chalk-making from the Cretaceous times until now.* But we have seen (p. 474) that many of the living deep-sea species are identical with, and nearly all extremely similar to, those found in the chalk of Cretaceous times. Thus there has been not only a continuity of chalk-formation, but also to some extent of the *chalk-fauna*, to the present time.

These facts were certainly unexpected, but, so far from shaking the foundations of geological science, as some have imagined, they are in perfect accordance with the fundamental principles of geological succession properly understood; as we now proceed to show:

1. The facts of identity have been exaggerated. Many of the *Foraminifera only are identical.* Among echinoderms the identity is generic, not specific. 2. In comparing higher with lower species, we find that the lower species are widely distributed both in space (geographically) and in time (geologically), and that the continuance or range in time becomes less and less in proportion as we rise in the scale. Thus, referring to diagram, Fig. 788, page 498 (under Tertiary), constructed to illustrate this point, we see that living species of mammals extend back only a little way into the Quaternary, living species of mollusks back to the beginning of the Tertiary, while living species of Foraminifera, as we might expect, extend back into the Cretaceous. 3. There is a necessary relation between fauna and external conditions. Changes in the latter determine corresponding changes in the former. Now, deep-sea conditions are evidently far less subject to change—far more continuous—than shallow-water and land conditions. For this reason, we should expect deep-sea faunæ to change very slowly. 4. But this cannot affect the geological chronology, *because this chronology*

rests almost wholly on the remains of shallow-water and land animals. Chalk is the only profound sea-bottom formation certainly known.. It is, therefore, wholly exceptional. 5. The reason it is exceptional is that, as a broad general fact, the present continents have been, through all geological times, steadily heaved upward out of the ocean, growing larger and higher; and, therefore, the successive additions have been nearly always *shallow marginal bottoms* and *shallow interior seas.* That the exception should occur in Europe rather than in America, too, is in keeping with the general character of the development of the European as contrasted with the American Continent. 6. Conversely, the fact that chalk is so exceptional is proof of the development of continents as indicated under the last head—proof that, as a general fact, the great inequalities of the earth's crust, which constitute land-surfaces and sea-bottoms, have remained substantially unchanged *in position* from the first, while steadily increasing in vertical dimensions.

General Observations on the Mesozoic.

The Mesozoic, and especially the Jurassic, is characterized by the culmination of two great classes of animals, viz., *Cephalopod Mollusks* and *Reptiles*, and one of plants, the *Cycads.* This is shown in the diagram on page 281. The culmination of reptiles is, of course, its most distinguishing characteristic. That it was preëminently an age of Reptiles, may be shown by a comparison of its reptilian fauna with that of the present day. There are *now*, on the *whole* face of the earth, only six large reptiles over fifteen feet long—two in India, one in Africa, three in America—and none over twenty-five feet long. In the *Wealden* and Lower Cretaceous of *Great Britain alone* there were five or six great Dinosaurs twenty to sixty feet long, ten to twelve Crocodilians and Enaliosaurs ten to fifty feet long, besides *Pterodactyls*, turtles, etc. (Dana). Again, in the *Cretaceous of the United States alone* the fullness of reptilian life was even greater; for 147 species of reptiles have been found, most of them of gigantic size. Among these were fifty species of Mosasaurs, some seventy to eighty feet long; many huge Dinosaurs, twenty to fifty feet long; besides Enaliosaurs, Pterosaurs, and gigantic turtles (Cope). These are *preserved!* But the known fossil fauna of any period is but a fragment of the actual fauna of that period. Not only did reptiles greatly predominate, but the age seemed to impress its reptilian character on all other higher animals existing at that time. The birds were reptilian birds, the mammals were reptilian mammals. All animals as yet were *oviparous* (birds and reptiles) or *semi-oviparous* (marsupials).

That the *climate* was then warm and uniform is sufficiently attested by the character of the fauna and flora. All great reptiles and all Cy-

cads and Tree-ferns are found now only in tropical or sub-tropical regions. This tropical fauna and flora were substantially similar in all latitudes in which the strata have been found—even as far north as Spitzbergen (Nordenskiold).[1] During the *latter* portion of the Cretaceous period, as indicated by the abundance of *deciduous* Dicotyls, the climate of North America had become cooler, being about 8° or 10° warmer than now.

Disturbance which closed the Mesozoic.—The disturbance which in America closed the Cretaceous period and the Mesozoic era was a *bodily upheaval of the whole western half of the continent*, by which the great interior Cretaceous sea, which previously divided America into two continents, was abolished, and the continent became one. At the same time the Wahsatch and Uintah Mountains were principally formed, and the eastern Rocky Mountain range greatly elevated.[2] If the end of the Jurassic was preëminently a time of *mountain*-making (Sierra revolution), the end of the Cretaceous was preëminently a time of *continent*-making. The disturbance, as usual with those which close an era, was probably to some extent *oscillatory*, i. e., the continent was probably higher and cooler during the latter part of the Cretaceous than during the subsequent Eocene. The change of physical geography was enormous, and the change of climate was doubtless correspondingly great. We ought to be prepared, therefore, to find, with the opening of the next era, a very great change in the organisms.

CHAPTER V.

CENOZOIC ERA—AGE OF MAMMALS.

This deserves the rank of a distinct *era*, and the corresponding rocks that of a distinct *system*, because there is here a great break in the rock-system, and a still greater break in the life-system. Between the rocks of the Cretaceous and Tertiary there is, in Europe, universal unconformity. In America, on the contrary, especially on the Western Plains, there seems to be in some places a continuous series of conformable rocks connecting the two eras (Hayden). *The record seems to be continuous.* Yet here, no less than in Europe, there is at a certain horizon a rapid and most extraordinary change in the life-system. This it seems impossible to explain on the theory of evolution unless we admit *periods of rapid evolution.* The reason why there is no general unconformity in America is, evidently, that the movement here was *continental,* and not

[1] *Geological Magazine*, November, 1875.

[2] It is well to observe in connection with the theory of mountain-formation given on page 262 that, until the end of the Cretaceous, the region of the Wahsatch was the western marginal bottom of the interior Cretaceous sea.

mere mountain-making and strata-crushing. Such continental movements, however, would produce very great changes in climate, and therefore in organic forms. The end of the Jurassic was a period of mountain-making, and therefore of unconformity—the end of the Cretaceous, a time of continent-making, and but little unconformity, but very great change of climate. Therefore, although the interval lost in America is far greater at the end of the Jurassic, the change of fauna and flora was far greater at the end of the Cretaceous.

General Characteristics of the Cenozoic Era.—As indicated by the name, modern history commences here; modern types were introduced or became predominant; the present aspect of field and forest commences, and the present adjustment of the relations of the great classes and orders was established. Then, as now, the rulers of the seas were great sharks and whales; the rulers of the land, mammalian quadrupeds; and the rulers of the air, birds and bats. Many of the genera and some of the species of both animals and plants were identical with those still living. The dominant class becomes now Mammals: Reptiles, therefore, in accordance with a necessary law, decrease in size and number, and thus find safety in a subordinate position. In some of these characteristics the Cenozoic era was anticipated in the Upper Cretaceous, in accordance with the law that the first beginnings of each age is in the preceding age.

Divisions.—The Cenozoic era, or age of Mammals, embraces two periods, viz.—1. The *Tertiary* and 2. The *Quaternary*. In the *Tertiary* all the mammals are now wholly extinct, but the invertebrate species are some of them still living, and an increasing percentage of living species appears as time progresses. In the *Quaternary* most, though not all, of the mammalian species are extinct, but most (ninety-five or more per cent.) of the invertebrate species are living. These facts are graphically represented in the following diagram, in which

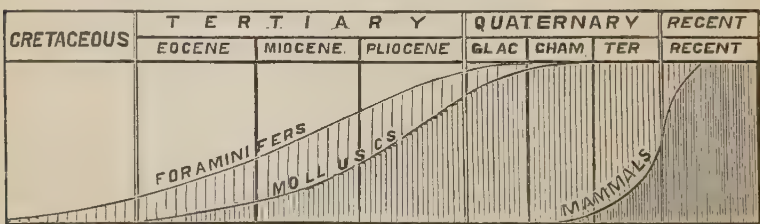


FIG. 788.—Diagram illustrating the Relative Duration of Lower and Higher Species.

the curved ascending lines are the *lines of appearance* of *living* species, and of *extinction* of *extinct* species of *Foraminifera*, of *molluscous shells*, and of *mammals*. In each case the lower shaded space represents living species appearing in small numbers, and increasing with the

progress of time; and the upper unshaded or less shaded space, previous species gradually dying out and becoming extinct. It is seen that *living* species of *Foraminifera* commenced in the Cretaceous, and very steadily increased in number; those of *shells* commenced in the earliest Tertiary, and increased somewhat more rapidly; while those of *mammals* commenced only in the Quaternary, and increased correspondingly rapidly. Also the *relative proportion* of living and extinct at any time is shown by comparing the amount of space above and below the line at that time. Also the relative *range in time* of low and high species, and the amount of overlapping of successive faunæ, are shown.

The mammalian class probably culminated near the end of the Tertiary or during the Quaternary period.

SECTION 1.—TERTIARY PERIOD.

Subdivisions.—We have already stated that the general differential characteristic of this period, as compared with the next, is that all the mammals, and most of the invertebrates, are extinct; but of the latter a percentage, small at first but increasing with the progress of time, are still living. It is upon this *percentage* of living shells that Lyell has based his division of the Tertiary period into three epochs—a Lower, Middle, and Upper Tertiary, or Eocene, Miocene, and Pliocene.

Tertiary period.
- Pliocene epoch, or Upper Tertiary = 50–90 per cent. living shells.
- Miocene epoch, or Middle Tertiary = 30 per cent. living shells.
- Eocene epoch, or Lower Tertiary = 5–10 per cent. living shells.

These percentages are expressed graphically in the diagram, Fig. 788.

Rock-System—Area in the United States.—On the Atlantic border, going southward, there is no Tertiary, except a small patch on Martha's Vineyard, off the coast of Massachusetts, until we reach New Jersey. From this point southward the Tertiary is a broad strip, about 100 miles wide, bordering the coast, and shown on the map (p. 289) by the space shaded with oblique lines running to the right. It constitutes the low-countries of the Southern Atlantic States. At its junction with the metamorphic region of the up-countries, there are in nearly all the rivers cascades which determine the head of navigation. Here, therefore, are situated many important towns, e. g., Richmond, Virginia; Raleigh, North Carolina; Columbia, South Carolina; Augusta, Milledgeville, and Macon, Georgia. The same strip of flat lands *borders* also the *Gulf*, expands, in the region of the Mississippi River, northward to the mouth of the Ohio, and then continues around the western border of the Gulf. In the Gulf-border region, however, the Tertiary is in contact below with the Cretaceous, instead of with metamorphic Silurian

and Laurentian, as on the Atlantic border. This whole Atlantic-border and Gulf-border Tertiary is, of course, a *marine* deposit.

In the *interior*, on the Plains and in the Rocky Mountain region, there are enormous areas of *fresh-water* deposit, some Eocene, some Miocene, and some Pliocene, which are of extreme interest.

Among the *Eocene* basins the most remarkable are: 1. The Green River basin. 2. The Uintah basins. Both of these are on the east side of the Wahsatch Mountains, and separated from each other by the Uintah Mountains, one being north and the other south of that range. The strata of the Green River basin are 6,000 to 8,000 feet thick.

Among the *Miocene* basins the most interesting are: 1. The *White River basin*, in Nebraska. 2. The *John Day basin*, of Oregon. This latter is 5,000 feet thick, but is largely overlaid by the great lava-flood of the Northwest. Patches of Miocene scattered about in Nevada basin show that this deposit once extended far south into Nevada and Eastern California (King).

Of *Pliocene* basins: 1. *Niobrara basin*, occupying partly the same locality as the Miocene *White River basin*, but far more extensive, reaching southward to the Gulf, and northward into British America. 2. In *Oregon* also there is a Pliocene basin, occupying partly the same region as the previous Miocene. 3. One recently discovered by Cope on the basin of the Rio Grande. 4. According to King, the Oregon and Nevada lake-deposit was in Pliocene times greatly extended, so as to cover the whole Basin region.

All these deposits are imperfectly lithified sand and clays in nearly horizontal position, and have been worn by erosive agencies in the most remarkable way, sometimes into knobs and buttes like potato-hills on a large scale, sometimes into castellated and pinnacled forms, which resemble ruined cities. These are the "*Mauvaises Terres*" or "Bad Lands" of the West (Fig. 789).

On the Pacific coast, a large portion of the Coast ranges from Southern California to Washington is Tertiary, as are also in many places the lowest foot-hills of the Sierras.

Physical Geography.—From what has been said of the distribution of the rocks of this age, it is easy to reconstruct in a general way the physical geography of the American Continent during the early Tertiary period. In the northern part the *Atlantic shore-line* was probably *beyond* the present line, for there is no Tertiary deposit visible there. The shore-line of that time crossed the present shore-line in New Jersey, then passed along the line of junction of the Tertiary with the Metamorphic, its waves washing primary shores all along the Atlantic coasts, as it does now in the northern portion only; then along the junction of the same with the Cretaceous. The whole low-coun-

tries of the Southern Atlantic States and the whole of Florida were then a sea-bottom. The *Gulf of Mexico* was far more extensive than now,

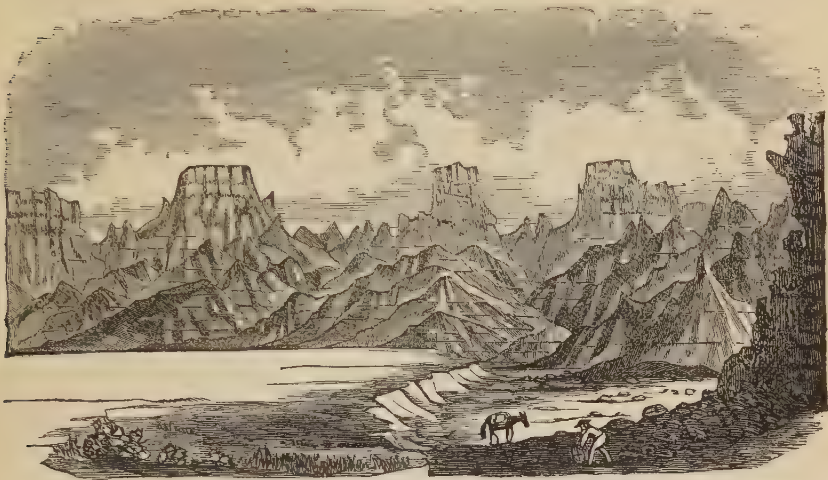


FIG. 789.—Mauvaises Terres, Bad Lands (after Hayden).

and especially it sent a wide bay northward to the mouth of the Ohio. The Mississippi River below that point did not then exist.

In the interior, in the region of the Plains, the Plateau, and the Basin, there were at different times immense *fresh-water lakes.* The

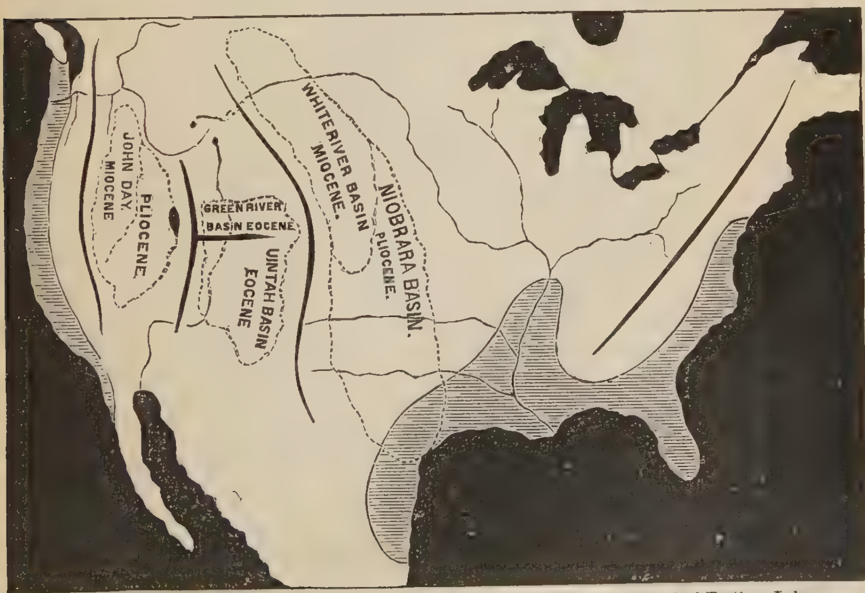


FIG. 790.—Map of Tertiary Times, showing Outline of Coast and Places of Principal Tertiary Lakes.

places of some of these are indicated on map, Fig. 790, in dotted outline. These outlines, however, are not intended to be accurate. These lakes drained some of them into the Mississippi, some into the Colorado, and some into the Columbia River.

The Pacific shore-line at that time was along the foot-hills of the Sierra range, and therefore the whole region occupied by the Coast ranges and the Sacramento and San Joaquin Valleys, and also portions of Western Oregon, were then a sea-bottom. These facts are roughly represented on map, Fig. 790. The positions of the principal mountain-chains, e. g., Sierra, Wahsatch, Uintah, the eastern border of the Rocky Mountains, and Appalachian, are represented, in order the better to locate the lakes. It will be observed that the continent is *nearly finished.*

Europe is now remarkable for its inland seas. It was much more so in Tertiary times.

Many great cities, as, for example, London, Paris, Vienna, are situated on Tertiary strata, partly because these strata are usually found on the borders of continents, and partly because they are often found in the course of great rivers, which once drained lake-basins.

Character of the Rocks.—The rocks of this period, along the Atlantic border and in the interior Plains and Rocky Mountain region, are mostly imperfectly lithified; but on the Pacific coast they are not only of stony hardness, but in many cases completely *metamorphic.* Much of the rock in the Coast Chain is scarcely distinguishable from the schists of the Palæozoic or still older periods. The reason is evident—metamorphism is closely connected with mountain-making, and mountain-making continued until the Tertiary only on the Pacific coast.

Coal.—Again, in the Tertiary rocks we find coal, although more usually in the imperfect condition called lignite. We have already stated that the Rocky Mountain coal-fields are by many referred to the Tertiary. We will not repeat these here. But there are others about which there is as yet no controversy. The *Coos Bay* coal, of Oregon, is probably Miocene-Tertiary. Again, Mr. Selwyn, the Geologist of Canada, has reported large fields of coal on the Qu'Appelle and the North Saskatchewan Rivers, covering an area of 25,000 square miles, a part, at least, of which he refers to the Tertiary. Much of this coal is of good quality. It seems most probable, however, that this is of the same age as the Fort Union coal, concerning the age of which there is so much discussion.

In Europe also an imperfect coal (lignite) is found in the Miocene in considerable quantity.

Life-System.

General Remarks.—We have already spoken of the great and rapid change in the life-system between the Cretaceous and the Tertiary, even where the two series of rocks are continuous and conformable. This

indicates, undoubtedly, a more rapid rate of evolution at that time. But it also indicates, as one cause of this rapid evolution, a *migration* of species brought about by changes in physical geography and climate, and the imposition of one fauna and flora upon another, and the extermination of one by the other. It is difficult to conceive of these sudden changes taking place otherwise. We shall speak more fully of this important point under the Quaternary.

The general character of the life-system of the Tertiary, as already said, was in the main similar to the present. Nearly all the genera and many of the species of plants and invertebrate animals were the same as now, and the difference in aspect would hardly be recognized by the popular eye; it was certainly not greater than now exists between different countries. It is only among Mammals that the difference would be very conspicuous.

Plants.

Among plants, nearly all the *genera of* Dicotyls, Palms, and Grasses, were the *same as now*, though most of the *species* are extinct. *The genera were the same as now*, but *not in the same localities.* On the contrary, the vegetation indicated a much warmer climate than exists now in the same localities. For example, if we regard the Lignitic as Eocene-Tertiary, instead of *Cretaceous*, as do paleontological botanists generally, then of about 250 species of plants found, a very large proportion were Palms, and many of them of great size; and among the Dicotyls many, like Magnolias, indicated a warm climate. Lesquereux thinks the climate of Fort Union was *then* similar to that of Florida and Lower Louisiana *now*. Again, in *Eocene* times there were fifteen species of Palms in Europe; and in the Tyrol the flora, according to Von Ettingshausen, indicated a temperature of 74° to 81° Fahr., and many of the plants are Australian in type. In the Pliocene, on the contrary, many European plants were like those in America at the present time.

During *the Miocene*, Europe was covered with evergreens such as could grow now only in the southernmost part; and that even as far as Lapland, and Iceland, and Spitzbergen. It has been estimated that the Miocene flora indicates a mean temperature of 16° to 20° higher than now exists in Middle Europe. In America, during the same epoch, Sequoias almost identical with the Big Tree and Redwood of California; and *Libocedrus*, one of them identical with the *L. decurrens* of California; and Magnolias similar to the *M. grandiflora* of the Southern Atlantic States; and *Taxodium distichum*, the cypress of the swamps of Carolina and Louisiana, all existed in Greenland, and most of them also in Northern Europe, and Iceland, and Spitzbergen. Heer estimates the temperature of Greenland in the Miocene as 30° higher than now.

These facts show not only a warm but a uniform climate, and probably also a *connection in high latitudes between the American and European Continents.* A similar connection, shown also by the vegetation, probably existed between Alaska and the Asiatic Continent at that time. Below we give figures of some Dicotyls and Monocotyls of American and European Tertiary.

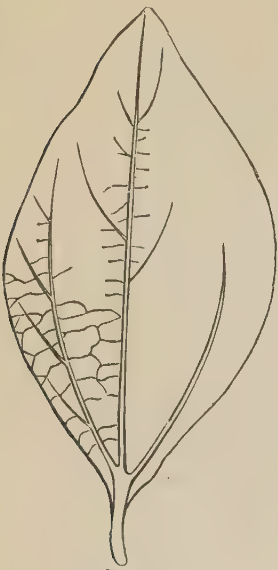


FIG 791.


FIG. 792.

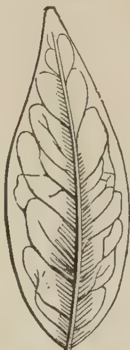


FIG. 793.


FIG. 794.


FIG. 795.

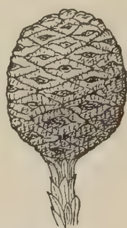


FIG. 796a.


FIG. 796b.

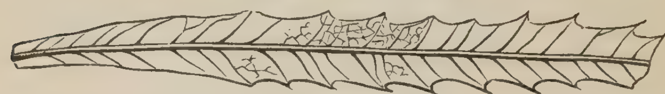


FIG. 796.

FIGS. 791–796b.—AMERICAN TERTIARY PLANTS (after Safford and Lesquereux): 791. Cinnamomum Mississippiense. 792. Quercus crassinervis. 793. Andromeda vacciniifoliæ affinis. 794. Carpolithes irregularis. 795. Fagus ferruginea—Nut. 796. Quercus Saffordi. 796a. Fruit of Sequoia Langsdorfii (after Heer). 796b. Leaf of Sequoia Langsdorfii (after Heer).

Another conclusion to be drawn from the foregoing facts is that, in the race of evolution, Europe seems to have distanced most other countries. The Australian flora is now only where the European flora was in Eocene times, and the American flora now where the European was in the Pliocene. The probable reason is that, in Europe, in these later geological times,[1] changes of physical geography and climate, and consequent migrations of species, were more frequent, and the struggle for life

[1] In *Cretaceous times* the flora of America seems to have been more advanced than that of Europe.

more severe. Australia especially, probably on account of its isolation, has advanced more slowly than most other countries. Many remnants of extinct faunæ and floræ exist there still.

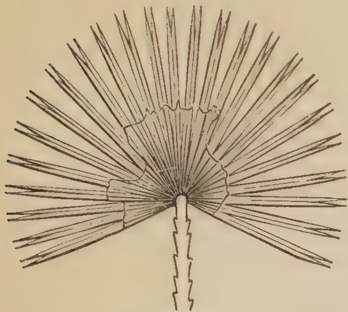


Fig. 797.

Fig. 798.

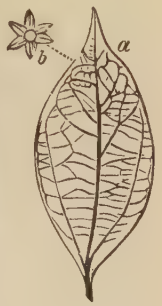


Fig. 800.

Fig. 799.

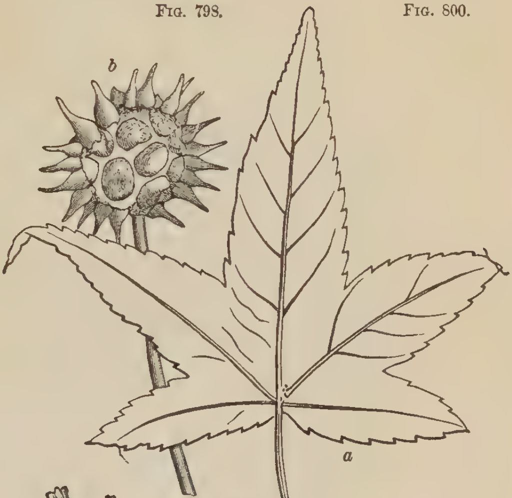


Fig. 802a.

Fig. 801.

Fig. 802.

Figs. 797–802a.—Plants of European Tertiary: 797. Chamærops Helvetica. 798. Sabal major. 799. Platanus aceroides: *a*, Leaf; *b*, Core of a Cluster of Fruits; *c*, Single Fruit. 800. Cinnamomum polymorphum: *a*, Leaf; *b*, Flower. 801. Acer trilobatum: *a*, Leaf; *b*, Flower; *c*, Seed. 802. Podogonium Knorrii. 802a. Liquidambar Europeum, from fenugreque: *a*, Leaf; *b*, Fruit (after Heer).

Diatoms.—If the *highest* of plants—Dicotyls and Monocotyls—were abundant, probably more abundant than now, so also were the lowest order of uni-celled plants—the *Diatoms*. Immense deposits, consisting

wholly of the siliceous shells of these microscopic plants, are found in the Tertiary. In Europe the Bohemian deposit is celebrated. It is fourteen feet thick, and every cubic inch of the material, according to Ehrenberg, contains 40,000,000,000 shells. The Richmond (Virginia) deposit is equally well known. It is thirty feet thick, and many miles in extent. Similar deposits are peculiarly abundant in California. They are found in at least a dozen localities where the Tertiary rocks prevail, as, for example, at San Pablo, in Shasta County, and near Monterey, the last deposit being fifty feet thick.

Some of the more remarkable forms of Diatoms are shown below in Fig. 803, which is a view under the microscope of the Richmond deposit.

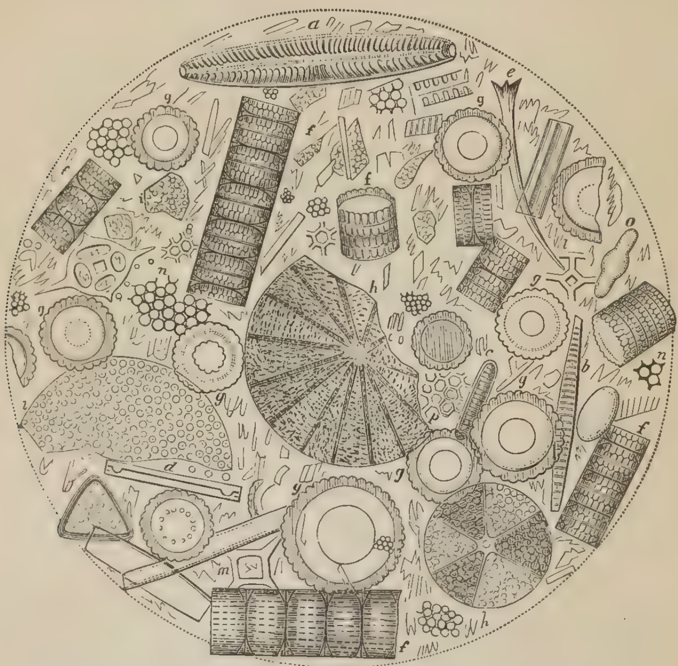


FIG. 803.—Microscopic View of Richmond Infusorial Earth (by Ehrenberg).

Deposits of this kind are usually called infusorial earths. They may often be recognized, even without microscopic examination, by their soft, *chalky* consistence, their *insolubility* in acids, and their extreme *lightness*.

Origin of Infusorial Earths.—It is well known that mud composed of diatom shells accumulates at the bottoms of ponds, and lakes, and sluggish streams. In the deepest parts of Lake Tahoe, where sediments do not reach, the ooze is composed wholly of infusorial shells. It

has been shown, also, by Dr. Blake,[1] that the deposits from hot springs of California and Nevada, even where the temperature is 163° to 174°, abound in Diatoms of the same species as those found in California infusorial earths. It is probable, therefore, that many of these deposits were made in hot springs and hot lakes, which, judging from the volcanic activity of that time, abounded in California then even far more than now. Dr. Blake thinks the infusorial earths of California are *Miocene.*

Animals.

As already stated, among Invertebrates there was a general similarity to the present fauna. Nearly all the genera, and many of the species, were identical with those still living. The relation between the various orders which prevail *now*, commenced *then.* The present basis of adjustment was *then* established. Then, as now, Brachiopods and Crinoids were nearly all gone, Echinoderms were nearly all free, and Bivalves were nearly all Lamellibranchs. Then, as now, naked Cephalopods and short-tailed Crustaceans greatly predominated. A glance at the following figures of Tertiary shells will show the general resemblance to those of the present seas.

In regard to the Invertebrates, there are only three or four points of sufficient importance to arrest our attention in a rapid survey.

Among *Rhizopods*, Nummulites (a foraminifer) abounded to an extraordinary degree. Eocene strata, many thousand feet thick, are formed of these shells. The Nummulitic limestone of the Alps extends eastward to the Carpathians, westward to the Pyrenees, and southward into Africa. It was largely quarried to build the Pyramids of Egypt. It occurs also extensively in Asia Minor and in the Himalayas.

Fig. 804.—Nummulina lævigata.

This limestone occurs in the Alps 10,000 feet, and in the Himalayas 15,000 feet, above the sea-level. We see, then, the immense changes which have occurred by mountain-making since the Eocene.

Among *bivalve shells*, common forms of the present day, such as the oyster, the clam (*Venus*), the scallop-shell (*Pecten*), etc., were very numerous, and some of very large size. Oysters especially seemed to have reached their maximum development in the Tertiary. The *Ostrea*

[1] *American Journal of Science*, III., vol. iv., p. 148.

Georgiana (Fig. 806) was ten inches long and four wide; the *Ostrea Caroliniensis* was of equal size, but shorter and broader. A specimen of the *Ostrea Titan* of California and Oregon now lies before us, which by

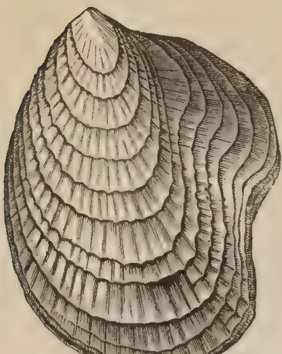


Fig. 805.

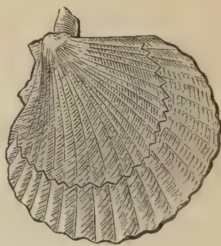


Fig. 807.

Fig. 806.

Fig. 809.

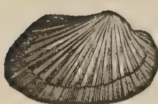


Fig. 808.

Fig. 810.

Fig. 811.

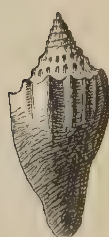


Fig. 812.

Figs. 805–812.—Eocene Tertiary Shells: 805. Ostrea sellæformis (after Meek). 806. Ostrea Georgiana (after Meek). 807. Pecten nuperum (after Wailes). 808. Anomalocardia Mississippiensis (after Conrad). 809. Umbrella planulata (after Wailes). 810. Turritella alveata (after Wailes). 811. Volutalithes dumosa (after Wailes). 812. Volutalithes symmetrica (after Wailes).

measurement is thirteen inches long, eight wide, and six thick (Fig. 813),

Fig. 813.

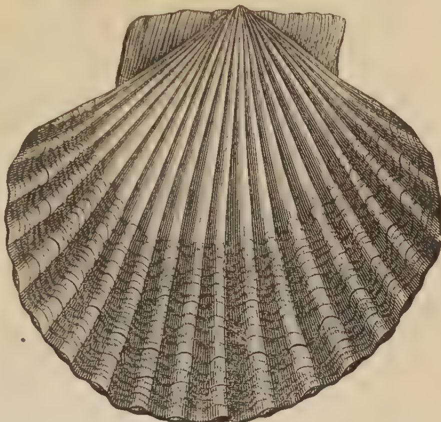


Fig. 814.

Fig. 815.

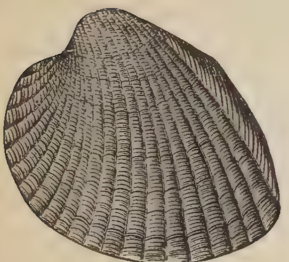


Fig. 816.

Fig 818.

Fig. 817.

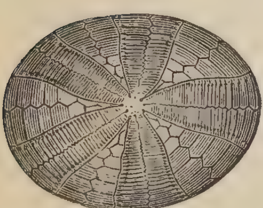


Fig. 819.

Figs. 813-819.—California Miocene Shells (after Gabb): 813. Ostrea Titan, × ⅓. 814. Pecten Cerrocensis, × ⅓. 815. Venus pertenuis. 816. Cardium Meekianum. 817. Cancellaria vetusta. 818. Ficus pyriformis. 819. Echinorachnis Breweranus.

and a specimen of *Pecten Cerrocensis* of California, nine inches across (Fig. 814). Among univalves also nearly all the forms are familiar. The illustrations are taken from the Eocene and Miocene. The Pliocene shells are almost undistinguishable from living shells, except by the practised eye. It seems useless to give them in an elementary work.

Insects.—There are several interesting points connected with this class which must not be omitted. We have usually found insects abundant in connection with luxuriant vegetation. During the Miocene, phenogamous vegetation was even more abundant than now; there was also extreme fullness of insect-life. All orders, even the highest, viz., Lepidoptera (butterflies—Fig. 821) and Hymenoptera[1] (bees, ants, etc.—Fig. 820), were represented.

In the Miocene of Europe, 1,550 species of insects have been found; and of these more than 900 species at Œningen in a stratum only a few

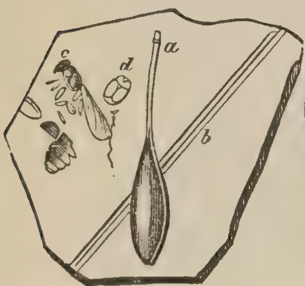


Fig. 820.

Fig. 821.

Figs. 820, 821.—Insects of European Miocene: 820. *a*, Pod of Podogonium Knorrii; *b*, Grass-leaf; *c*, Formica lignitum; *d*, Hister coprolithorum. 821. Vanessa Pluto.

feet thick (Lyell). In places the stratum is black with the remains of *insects*. The same stratum is also full of leaves of *Dicotyls*, of which Heer has described 500 species. Mammalian remains and fishes are also found in them.

It is interesting to inquire the conditions under which these strata were formed and filled with these remains. On Lake Superior, at Eagle Harbor, in the summer of 1844, we saw the white sands of the beach blackened with the bodies of insects of many species, but mostly beetles, cast ashore. As many species were here collected in a few days, by Dr. J. L. Le Conte, as could have been collected in as many months in any other place. The insects seem to have flown over the surface of the lake; to have been beaten down by winds and drowned, and then slowly carried shoreward and accumulated in this harbor, and finally cast ashore by winds and waves. Doubtless, at Œningen, in Miocene times, there was an extensive lake surrounded by dense forests; and the insects drowned in its waters, and the leaves strewed by winds on its surface, were cast ashore by its waves. Heer believes

[1] See Appendix.

also that carbonic-acid emissions helped to destroy, and deposits of carbonate of lime to preserve, the insects. Over five hundred of the Œningen insect-species were beetles.

Among the insects found at Œningen, Switzerland, and Radoboj, Croatia, are a great many *ants* (Fig. 820). In all Europe, there are now about fifty species of ants. Heer found in the Miocene of Œningen and Radoboj *more than* 100 *species*.[1] And, what is very remarkable, nearly all are *winged* ants. Ants of the present day are male, female, and neuter. The males are winged throughout life, and never live in the nests, but soon perish. The females are also winged until they are fertilized; then they drop their wings and live in communities in a wingless condition ever afterward. The neuters are always wingless, and therefore always live in nests or in communities. It is probable that ants at first were only winged males and females, living in the open air like other insects. The wingless condition and the neutral condition are both connected with their peculiar social habits and instincts, and have been gradually developed along with the development of their habits and instincts. It is probable that all these remarkable peculiarities, viz., the wingless condition, the neutral condition, the wonderful instincts, and organized social habits, have been developed together *since the Miocene epoch*.

In the fresh-water Miocene of Auvergne, France, there is a remarkable stratum called *indusial limestone*, because it is largely composed of the cast-off hollow cases (indusia) of the caddis-worm or larva of the caddis-fly (*Phryganea*), cemented together by carbonate of lime. The number of these cases is countless. The caddis-worm of the present day forms for itself a hollow cylindrical case, of bits of stick or pieces of shell, or sometimes of whole small shells, binding these together by means of a kind of web. In this hollow cylinder it lives, only putting out the head, and two or three first joints of the body to which the feet are attached, in walking. When they complete their metamorphoses, they leave their shells. Fig. 824 is a recent caddis-worm with its case of small shells stuck together; Fig. 823 are indusia of the Miocene caddis-worm; and Fig. 822 is the limestone in place, *a* being the indusial layer.

In Auvergne, in Miocene times, there existed a shallow lake, in which carbonate of lime was depositing, as in many lakes of the present day. In this lake lived myriads of caddis-worms, and their indusia accumulated for countless generations.

In the Tertiary strata, about the shores of the Baltic, and also in Sicily, in Asia Minor, and several other localities, usually associated with lignite, are found masses of amber. This substance is a fossil resin of several species of Conifer, especially *Pinites succinifer*. It is often quite transparent, and inclosed within may be seen, perfectly pre-

[1] Pouchet, *Popular Science Monthly*, June, 1873.

served, insects of many kinds. Over 800 species of insects, and fragments of many species of plants, have been found thus inclosed. The degree of preservation is marvelous; even the most delicate parts, the slender legs, the jointed antennæ, and the gauzy wings, are perfect. The manner in which these insects were entangled, inclosed, and preserved, may be easily observed even at the present day. The gum issuing from Conifers is at first in the form of semi-liquid, transparent tears. Flies, gnats, etc., alighting on these, stick fast, and by the run-

Fig. 822.

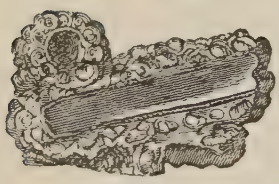


Fig. 823.

Fig. 824.

Figs. 822–824.—822. Indusial Limestone interstratified with Fresh-Water Marls. 823. A Portion (natural size) showing the Phryganea Cases. 824. Recent Larva of a Phryganea, with its Case.

ning down of further exudations are enveloped and preserved forever. The legs, both in the modern and the fossil resin, are often found broken by the struggles of the insects to extricate themselves. The insects of the Tertiary, like the plants, show a decided tropical character.[1]

Fishes.—The present relation between the three great orders of Fishes—Teleosts, Ganoids, and Placoids—was first fairly established in the Tertiary. Teleosts were first introduced in the Cretaceous, but

[1] See Appendix.

only in the Tertiary did they become very abundant. Ganoids, on the contrary, became fewer in number ; they sank into their present subordinate position. Among Placoids, the Hybodonts are gone, the Cestracionts are few in number, but the Squalodonts reach their maximum development, both in number and size. In the marine Tertiary of the

Fig. 825.

Fig. 826.

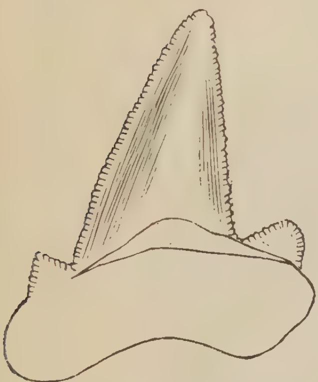


Fig 827.

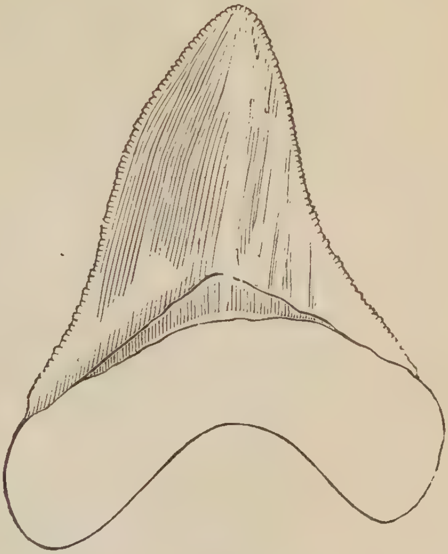


Fig. 828.

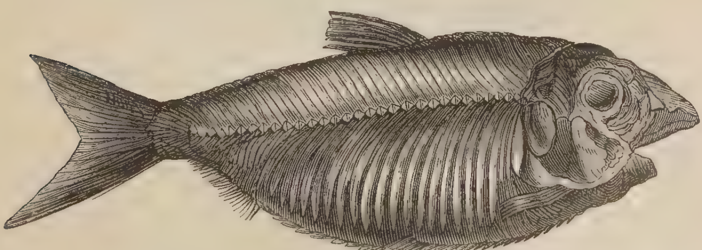


Fig. 829.

Figs. 825–829.—Tertiary Fishes—*Placoids :* 825. Lamna elegans (after Agassiz). 826. Notidanus primigenius (after Agassiz). 827. Carcharodon augustidens (after Gibbes). 828. Carcharodon megalodon, × ½ (after Gibbes). 829. Clupea alta (after Leidy).

Atlantic border, both Eocene and Miocene, sharks' teeth are found in immense numbers, and of very great size. Some of the triangular teeth of the *Carcharodon megalodon* (Fig. 828) are found six and a half inches long and six inches broad at the base. The owners of such teeth must have been fifty to seventy feet long. Some of the more com-

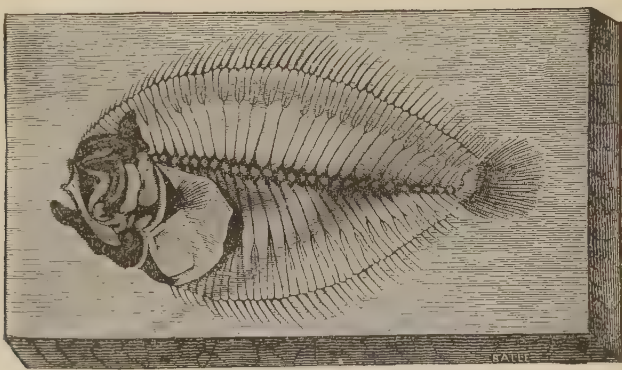


FIG. 830.

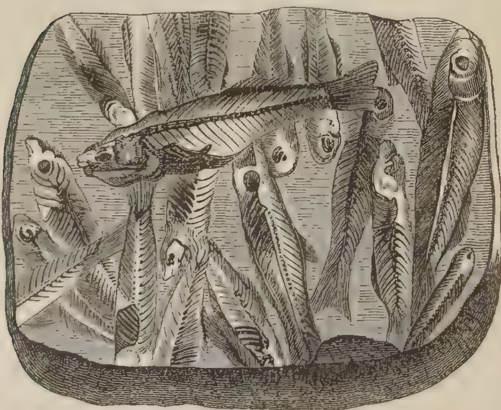


FIG. 831.

FIGS. 830, 831.—TERTIARY FISHES—*Placoids:* 830. Rhombus minimus, Lower Eocene. 831. Lebias cephalotes, Miocene.

mon forms of sharks' teeth of the American Tertiary, and Teleosts from American and European Tertiary, are given above.

Reptiles.—The age of Reptiles is past. The huge Enaliosaurs, Dinosaurs, Mosasaurs, and Pterosaurs, are all extinct. Their class is now represented by Crocodiles, Turtles, Snakes, and Frogs, though their place

as rulers is supplied by Mammals and Birds. Five species of Snakes, some of them eight feet long, and nine Crocodilians, have been found in the Eocene of Wyoming, and several also in Europe. In the Miocene of Europe, at Œningen, a Salamandroid Amphibian was found and described in 1728 by Scheuchzer, a physician and naturalist, professor in the University of Altorf. He gave it the title "*Homo Diluvii Testis*," believing it to be the skeleton of a human being destroyed by the deluge. The length was about four feet. It was reserved for Cu-

FIG. 832.

FIG. 832a.

FIGS. 832, 832a.—832. Andrias Scheuchzeri, Miocene of Switzerland, $\times \frac{1}{10}$ (after Heer). 832a. Andrias Japonica, a living Salamander from Japan, $\times \frac{1}{10}$ (after Heer).

vier to show that the fossil was not human, though the name *Andrias Scheuchzeri* (Fig. 832) had become permanently attached to it through Scheuchzer's mistake. A living species of the same genus is now found in Japan, and is of gigantic size. A representation of it is given in Fig. 832a, for comparison with its fossil precursor. The Miocene of the Himalayas furnishes a gigantic turtle (*Colossochelys Atlas*), the carapace of which was twelve feet long and eight feet wide, and seven feet

high in the roof, and the whole animal was probably twenty feet long. Over sixty species of Tertiary turtles, and eighteen or twenty species of crocodiles, have been described from foreign countries (Dana).

The Crocodilians, the highest order of reptiles, first appeared in the Triassic, but only in generalized forms—*Stagonolepis*, *Belodon*, etc.—which closely connected them with the Lizards. From this early form Huxley has traced with consummate skill the gradual differentiation of this order, in the position of the posterior nares, the structure of the head and the form of the vertebral bodies, step by step through the Jurassic, Cretaceous, to the Tertiary, where the type reached its perfection.

Birds.—The class of Birds in the Cretaceous was represented only by the *reptilian* birds and ordinary *water* birds. Now, in the Tertiary, however, the reptilian birds—vertebrated-tailed and socket-toothed—have disappeared. The bird-class is fairly differentiated from the reptilian class, and the connecting links destroyed. Birds of all kinds now appear—land-birds as well as water-birds. In *America*, among land-birds, woodpeckers, owls, eagles, etc., have been discovered and described by Marsh. The number of species found in Europe is much greater than in America. The Miocene beds of Central France alone have, according to Milne-Edwards, afforded seventy species. The Miocene *birds*, like the *plants* and *insects*, show a decided tropical character. "Parrots and Trogons inhabited the woods; Swallows built, in the fissures of the rocks, nests in all probability like those now found in certain parts of Asia and the Indian Archipelago; a Secretary-bird, nearly allied to that of the Cape of Good Hope, sought in the plains the serpents and reptiles which at that time, as now, must have furnished its nourishment. Large Adjutants, Cranes, Flamingoes, Palæolodi (birds of curious forms intermediate between Flamingoes and ordinary Grallæ), and Ibises, frequented the margins of the water where insect-larvæ and mollusks abounded. Pelicans floated on the lakes; and, lastly, Sand-grouse and numerous Gallinaceous birds assisted in giving to this ornithological population a strange physiognomy which recalls to mind the descriptions given by Livingstone of certain lakes in Southern Africa."

Recently a toothed bird has been found in the London clay (Eocene), and named by Owen *Odontopteryx* (Fig. 833). But this is not a true *socket-toothed* bird. The so-called teeth are only dentations of the bony edge of the bill.

In 1876 Cope published the discovery of a gigantic bird from the lowest Eocene of the San Juan basin. The *Diatryma gigantea*, according to Cope, combines the characters of the Cursores (ostrich family) with those of the extinct Gastornis of the Paris basin (p. 518). Judging from its foot, it was double the size of an ostrich.

This is the first example of extinct Cursores found in North America (Cope).

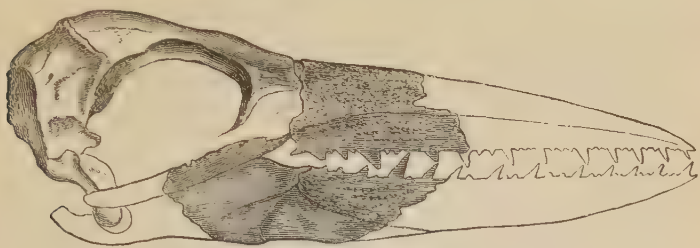


FIG. 833.—Skull of Odontopteryx toliapicus, restored (after Owen).

Mammals—General Remarks.—One of the most noteworthy facts connected with the first mammals is the apparent suddenness of their appearance in great numbers. We have already seen small marsupials quite abundant in the Mesozoic, but no trace of *true* mammals. In fact, the existence of these would seem to be incompatible with the reign of the huge reptiles. But, with the opening of the Eocene, the earth seems to swarm with mammals. And this is true not only in Europe, where the unconformity of strata indicates a lost interval at this point of the history, but also on the Western Plains and Rocky Mountain region, where the Cretaceous seems to graduate insensibly into the Tertiary. Upon any theory of evolution this can be accounted for only by supposing the period between the Cretaceous and Tertiary to have been one of very *great rapidity of change* of organic forms—this rapidity of change being the result partly of the pressure of changed climate, and partly of migration of species and the consequent struggle for life between different geographical faunæ.

True placental mammals not only appear suddenly and in great numbers, but of nearly all orders, even the highest except man, viz., monkeys. These, however, are not typical monkeys, but lemurs, which may be regarded as a generalized form, connecting monkeys with other orders. In the oldest Eocene beds (Wahsatch beds of the Green River and San Juan basins), Cope finds eighty-seven species of vertebrates, two-thirds of which are mammals. In the Fort Bridger beds of the Green River basin (Middle Eocene), Marsh finds 150 species of vertebrates, of which the larger number are mammals, some Herbivora, some Carnivora, and some Lemurine monkeys. The same species do not continue through the Tertiary. On the contrary, the mammalian fauna changes completely several times in the course of that period.

One general characteristic of the early mammalian fauna is the predominance of Herbivora. Especially is this true of the Cuvierian order *Pachyderms*, an order which now includes such diverse forms as ele-

phant, rhinoceros, hippopotamus, tapir, hog, horse ; and still more especially is this true of *tapir-like Pachyderms.* But there is much reason to believe that the very first Tertiary mammals were far more generalized in structure than any family of mammals now living.

The Tertiary mammals are of so great interest from the evolution point of view, that we must dwell upon them somewhat in detail. But

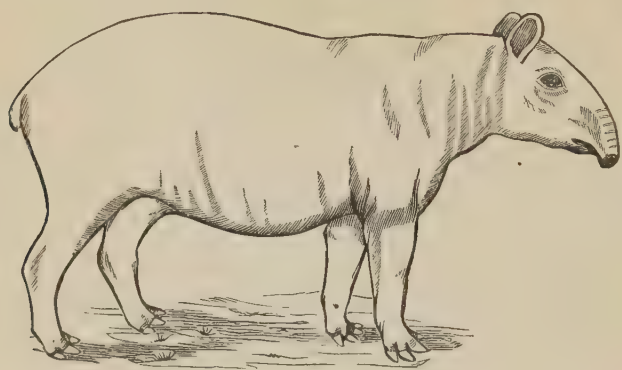


FIG. 834.—Tapirus Indicus.

it seems impossible to present selections from the immense mass of material at hand in an interesting manner, except by taking a few classic localities from different epochs and different countries, and briefly describing what has been found in each. We will commence with some foreign localities, because these were first discovered:

1. Eocene Basin of Paris.—This basin has been made celebrated by the labors of the immortal Cuvier. The discovery in the early portion of the present century of the rich treasures imbedded in the strata of this basin, and the consummate skill with which they were worked up by Cuvier, gave an incredible impulse to geology. Fifty species of mammals, of which forty species were tapir-like; ten species of birds, among which one, the *Gastornis*, was a huge wader as large as an ostrich ; besides reptiles, fishes, and shells in abundance, were discovered. In Eocene times the Paris basin seems to have been an estuary full of shells and fishes, etc., into which the bodies of birds and mammals were drifted. Among the many remarkable mammals we will select two as types, viz., the *Palæothere* and the *Anoplothere.*

The Palæothere, like the Rhinoceros and like some of the earlier representatives of the horse family, had three hoofed toes on all the feet. It is usually supposed to have had also the general form and the short flexible snout of a tapir,[1] and it is with this family that Cuvier

[1] The tapir has three toes on the hind-foot, and four on the fore-foot, but the outer one is small and not functional.

supposed it has its nearest alliance. The figure below is Cuvier's restoration, and until recently subsequent discoveries seemed to confirm its

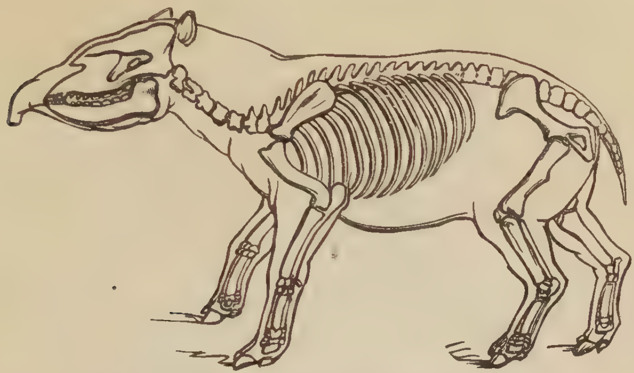


FIG. 835.—Restoration of Palæotherium magnum (after Owen).

general truthfulness.[1] In 1874, however, the discovery of a complete skeleton showed that the restoration of Cuvier is far from correct, and

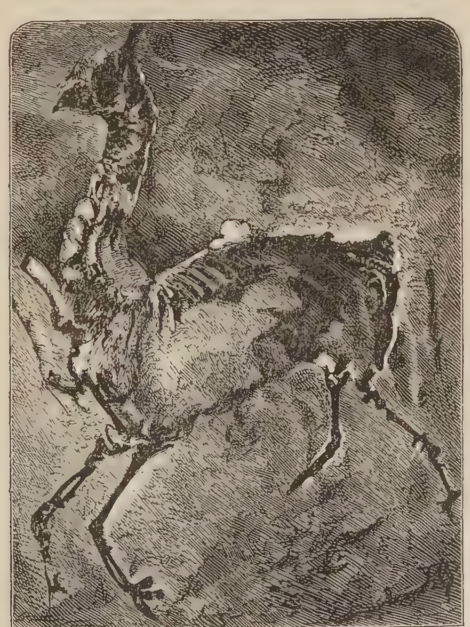


FIG. 836.—Palæotherium magnum (recently-discovered skeleton).

that the neck and limbs were much longer than had been supposed. In

[1] Owen, "Paleontology," p. 365.

general form it seems to have been more like the horse family than the tapirs.

The Anoplothere was a slender and graceful animal without snout, and possessing only two toes, like ruminants. Most of its characters,

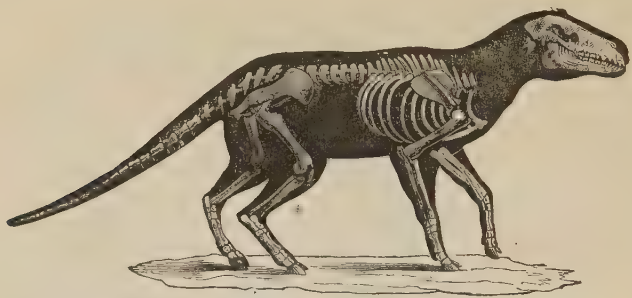


FIG. 837.—Anoplotherium commune, restored.

however, allied it to the tapirs. It was, therefore, a remarkable connecting link between the tapirs and ruminants.

2. **Siwalik Hills, India—Miocene.**—Near the base of the Himalayas occurs a range of hills which are composed of fresh-water Miocene strata. They are extremely rich in vertebrate and especially in mammalian remains, which have been thoroughly studied by Falconer. Eighty-four species of mammals are described from this locality. They are of great variety of forms, both Carnivora and Herbivora, but the latter are most abundant. Among these, perhaps the two most remarkable are *Dinotherium* and *Sivatherium*.

FIG. 838.—Head of Dinotherium giganteum, greatly reduced.

The *Dinothere* has been found also in the European Miocene. It was a huge animal, with a skull three feet long, to which was attached a proboscis. The lower jaw was bent downward, and carried two long, tusk-like teeth, projecting also downward. The whole height of the head, from the points of these lower teeth to the top of the cranium, was five feet.

Recently a perfect pelvis has been found, showing the great massiveness of these bones, and showing also, in these huge animals, the existence of *marsupial bones.*[1] This strange animal combined, in the structure of its head, the characters of Elephant, Hippopotamus, Tapir, and Dugong; but it also had affinities with marsupials. It was *the earliest of Proboscidians.*

[1] *American Journal of Science*, II., vol. xxxviii., p. 427.

The *Sivathere* was a *four-horned antelope*, of elephantine size and some elephantine characters. The four-horned antelope of the present day lives in the same locality, but is a comparatively small animal, with two short conical horns from the front part of the frontal bone, and two somewhat longer ones in the usual place on the back part of the same bone. The *Sivathere*, on the other hand, was of elephantine height, though of slenderer form, with two short conical horns in front, and two large, palmately branching ones behind. The form of the nose-bones suggests the existence of a snout. The feet and legs were clearly those

Fig. 839.—Head of a Sivatherium giganteum, greatly reduced.

of a Ruminant. It seems to have combined the characters of a Ruminant and a Pachyderm. The *Bramathere* was a similar animal, of equally gigantic size, found in strata of the same age.

In the same locality were found also three species of Mastodons, seven species of Elephants, one of them *E. ganesu*, remarkable for the prodigious length and size of its tusks; three species of the Horse family; five species of Rhinoceros; four to seven species of Hippopotamus, and three species of hog; also, Anoplotheres, Camels, Camelopards, Oxen, Sheep, Antelope, Musk-ox, Monkeys, etc; also, many Reptiles, among which were narrow-nosed Crocodiles, like the *Gavials* now living in the Ganges, and the huge Turtle, *Colossochelys*, already mentioned (p. 515).[1]

In the Miocene and Pliocene of Europe are first found remains of that most destructive of carnivores, the sabre-toothed tiger—*Machai-*

[1] See Appendix.

rodus (Fig. 840). In the Miocene of Europe, also, the first *true Monkeys* were introduced (Flower).

Perhaps it is well to call attention now to the fact that, while the tapir-like Pachyderms predominate in the *Eocene*, the huge forms, e. g.,

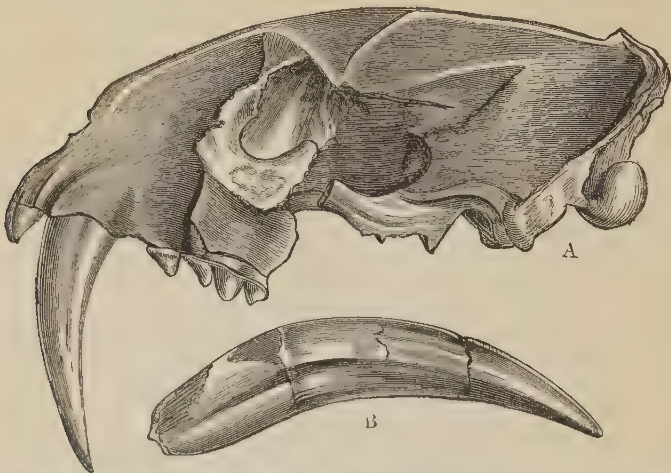


FIG. 840.—*A*, Skull of Machairodus cultridens, without the lower jaw, reduced in size; *B*, Canine Tooth of the same, one-half the natural size. Pliocene, France.

Rhinoceros, Hippopotamus, and Proboscidians, were first introduced and immediately became abundant in the *Miocene*.

American Localities.—3. Marine Eocene of Alabama.—We select this as an example of American marine Eocene. At *Claiborne*, Alabama, according to Lyell, there occur no less than 400 species of *shells*, besides many *Echinoderms*, and abundance of *sharks' teeth*. But the most remarkable remains found there are those of an extinct whale—*Zeuglodon cetoides*—so called from the yoke-like form of the double-fanged molar teeth, which were six inches in length (Fig. 841). The skull was long and pointed (Fig. 842), and set with the double-fanged teeth behind and conical in front. The vertebræ, which are in such abundance that they are used for making fences and even burned by farmers to rid the fields of them, are, some of them, eighteen inches long and twelve inches in diameter (Dana), and the vertebral column has been found in place nearly seventy feet long (Lyell). The animal must have been more than seventy feet long, and the remains of at least forty individuals have been found (Lyell). They have

FIG. 841.—Tooth of Zeuglodon cetoides, × $\frac{1}{2}$ (after Gaudry).

been found in southern Georgia as well as in Alabama, and probably their range was quite extensive.

This animal is peculiarly interesting as the first appearance of the very distinct order *Cetacea*. No intermediate links have yet been found connecting this with other orders of mammals, or with the great

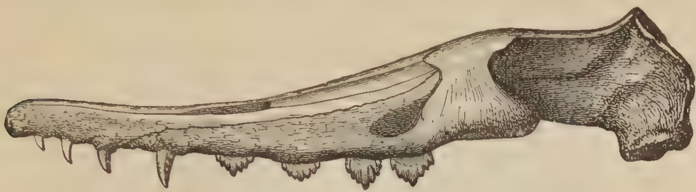


FIG. 842.—Head of Zeuglodon cetoides, × $\frac{1}{10}$ (after Gaudry).

reptiles. And yet, from their large size and marine habits, they are more likely than land mammals to have been found, if they existed in earlier or Cretaceous times.

The Atlantic and Gulf border strata are of course all marine, and therefore contain very few land-animals. It is to the *fresh-water basins* of the *interior* that we must look for a full record of the mam-

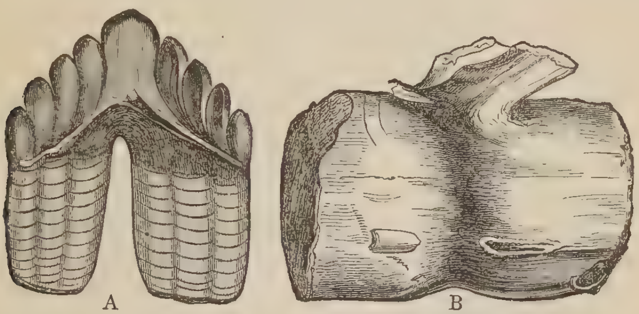


FIG. 843.—Vertebra and Tooth of Zeuglodon cetoides, reduced.

malian fauna of America in Tertiary times. These basins furnish the fullest and most continuous record of the whole Tertiary which has ever yet been found. It will be best to take them in the order of their age, as we can thus best show the evidences, if any, of derivation of the later from the earlier faunæ.

4. Green-River Basin—Wahsatch Beds—Lower Eocene.—About eighty-seven species of vertebrates have been found by Cope in the San Juan basin, of which fifty-four are mammals, one bird (*Diatryma*), twenty-four reptiles, and eight fishes. A large number of mammals have also been found in beds of the same horizon in the Green River basin. These beds have been shown by Marsh to be the equivalent of the lowest Eocene of England and France, and therefore contain the

very earliest known true mammalian fauna. In both countries they are characterized by the occurrence of the remains of animals of the genus *Coryphodon* (peak-tooth), one of the most generalized forms of mammals both in tooth-structure and in foot-structure yet known. They were five-toed Ungulates, having the full number of foot-bones unmodified, and a general structure connecting the more generalized forms of Herbivores, such as tapirs, with the more generalized Carnivores, such as bears (Cope). The genus Coryphodon includes seven or eight Ameri-

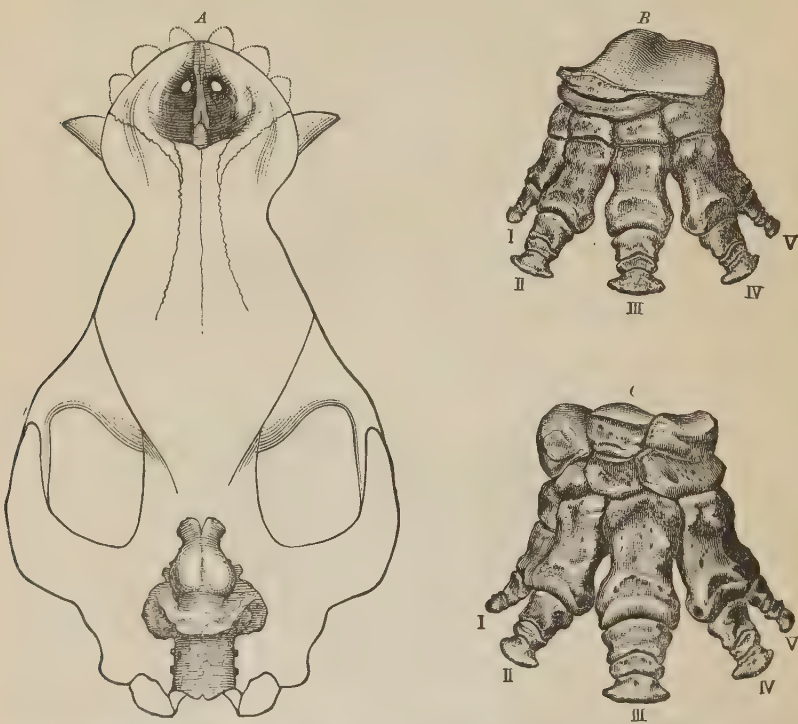


FIG. 844.—Coryphodon Hamatus (after Marsh): *A*, Head, showing form of the brain, × $\frac{1}{8}$; *B*, Hind-foot; *C*, Fore-foot, × $\frac{1}{8}$.

can species. The average size was about that of a tapir; some were smaller, and some twice as large (Marsh). These generalized forms have been put into a distinct family called *Coryphodontidæ* by Marsh.

5. **Green River Basin—Bridger Beds—Middle Eocene.**—From this wonderful fresh-water deposit there have been described by Marsh, Cope, and Leidy, 150 species of vertebrates, of which the larger number are mammals. This shows a marvelous abundance of mammalian life in this early Tertiary time. The most numerous of these are tapir-like animals, such as *Hyrachyus*, *Limnohyus* (*Palæosyops*—Fig. 846), etc.;

but the most formidable are the *Dinocerata*, an order established by Marsh, and including the genera *Dinoceras* (Marsh), *Uintatherium* (Leidy), and *Tinoceras* (Marsh), or *Loxolophodon* (Cope). The remains of more than one hundred and fifty distinct individuals of this order have been obtained from the Middle Eocene of Wyoming and deposited in the Museum of Yale College, where they have been carefully studied.

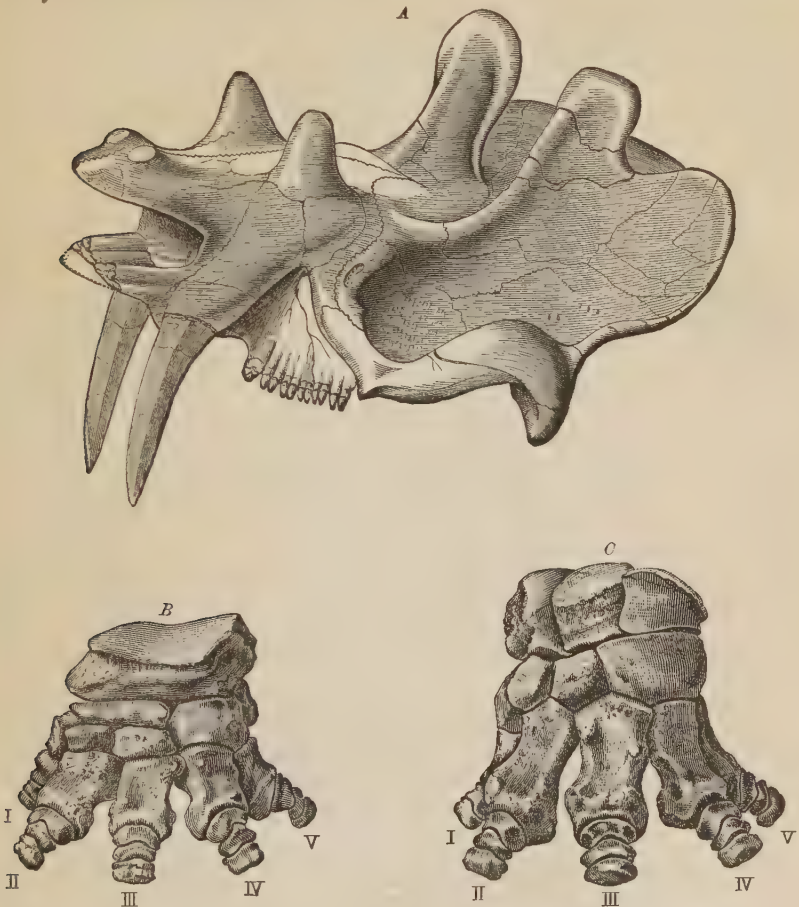


FIG. 845.—Dinoceras mirabile, × 1/8 (after Marsh): *A*, Skull; *B*, Hind-foot, × 1/5; *C*, Fore-foot, × 1/5.

The type genus of this order is the Dinoceras. Almost every bone in the skeleton of this animal is now known, and the restoration by Professor Marsh, shown in Fig. 845a, gives a clear idea of its structure. Although elephantine in size, there is no evidence in the skull of the existence of a proboscis; the proportions of the neck and fore-limbs, furthermore, show that its presence was unnecessary. Three

pairs of horns are indicated by the projecting cores (Fig. 845), one pair of which stood far in front on the nasal bones, another on the maxillary bones immediately above the canines, and a third and much larger pair farther back on the parietal bones. This last pair were sheathed with thickened integument, which may have developed into true horn, as in the Prong-horned Antelope. The three pairs of elevations are present in both sexes, but proportionally smaller in the females. In addition to these formidable weapons, both sexes were provided with canine tusks, those of the males being very powerful, in some cases seven or eight inches in length.

The largest, most specialized, and latest of the Dinocerata was the huge monster Tinoceras. The head of this animal was four feet in length, and the horn-cores much longer than in Dinoceras.

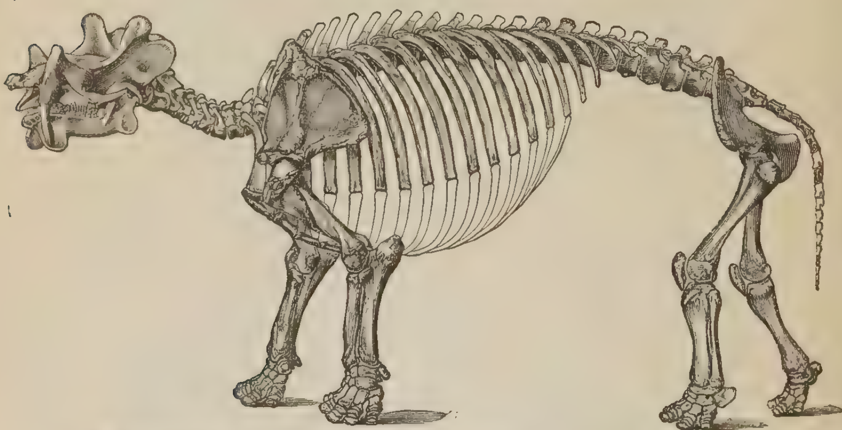


FIG. 845a.—Restoration of Dinoceras mirabile (after Marsh). One twenty-fifth natural size.

The animals of this entire order seem to have been quite abundant for a short time during the latter part of the Middle Eocene. They then became extinct, leaving apparently no successors, though possibly the Elephant tribe of to-day may be their greatly modified descendants. Their feet were provided each with five toes (Fig. 845), and the brain was proportionally smaller than in any other land mammal.

Another extraordinary group of animals discovered by Marsh in the Eocene beds has been placed by him in a new order (called *Tillodontia*). These animals combine the head of a bear with the incisors of a Rodent and the general characters of Ungulates. The order must be regarded, therefore, as a remarkable generalized type. The head and brain of the *Tillotherium* are given in Fig. 847.

The first appearance of the horse family (*Equidæ*) is in the Eocene.

First of all in the Lower Green River or *Coryphodon beds* appears the *Eohippus* (earliest horse), a small animal no bigger than a fox, having three toes on the hind-foot, and four perfect ones on the fore-foot, like

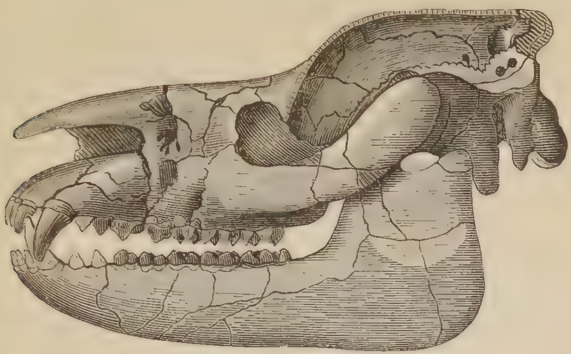


FIG. 846.—Limnohyus (Palæosyops) (after Leidy).

the tapir, and a rudimentary fifth toe; then in Green River *Bridger beds*, the *Orohippus* (mountain-horse), similar to the last in size, but wanting the fifth toe.

Although the Herbivores predominated, there were many mammals belonging to other orders. For example, there were species allied to

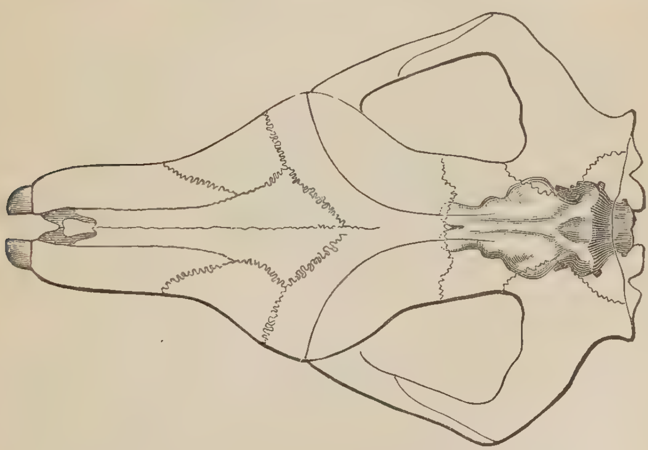


FIG. 847.—Skull and Brain of Tillotherium fodiens, × ½ (after Marsh).[1]

the Cat, Wolf, and Fox; also, Bats, Squirrels, Moles, and Marsupials; also many Monkeys allied to the Lemurs, Marmosets, etc., but more generalized than any living Lemur.

[1] See Fig. 847a, in APPENDIX.

6. Mauvaises Terres of Nebraska—White River Basin—Miocene.— From this, the first discovered of the fresh-water basins of the West, have been collected by Hayden, and described by Leidy, at least forty different species of mammals, among which twenty-five are Ungulates, eight Carnivores, and most of the remainder Rodents. All of the species, and many of the families, are entirely different from those found in the preceding epoch. Although the tapir-like animals still prevail, the deer, camel, and horse family are also abundant, as seen in the following schedule:

Carnivores.........	Hyena. Wolf. Tiger. Panther.	Allies.
Ungulates..........	Rhinoceros family. Brontotheridæ. Tapir-like animals. Deer family. Camel " Horse "	
	Rodents.	
	Turtles.	

Among the most remarkable ungulates of this time were the *Brontotheridæ.* This family, according to Marsh, includes the *Brontotherium, Menodus* (*Titanotherium*), and several other genera. They were animals of elephantine size, and armed with at least two horns on the

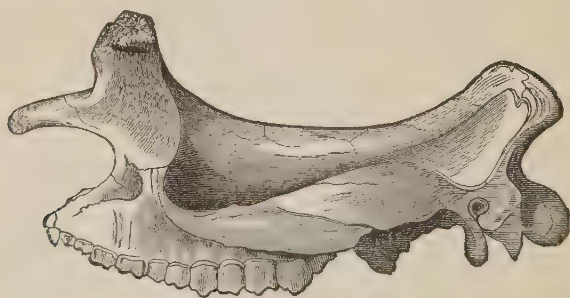


FIG. 848.—Skull of Brontotherium ingens (after Marsh).[1]

maxillaries. Their nearest allies were the Rhinoceros and the Tapir, but they had affinities also with the Dinocerata of the Eocene.

The *Oreodon* is another very remarkable animal, intermediate between the hog, the deer, and the camel, which at this time inhabited the whole continent from Nebraska to Oregon. A head of one is shown below. The Miocene deposits of Oregon are equally rich in all the families mentioned above. Among carnivores, besides many species of the Cat family, Cope found ten species of dogs.

[1] See Fig. 848a, in APPENDIX.

7. **Mauvaises Terres—Niobrara Basin—Pliocene.**—Nearly in the same locality as the last, but extending much farther south, occur lake-

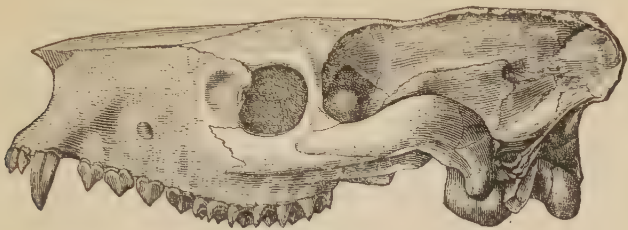


FIG. 849.—Eporeodon major, × ¼ (after Marsh).

deposits of the Pliocene epoch full of mammalian remains; but these mammals, though occurring in the same locality, belong to species entirely different from those of the Miocene. Among the Ungulates there is a Rhinoceros as large as the Indian species; an Elephant (*E. Americanus*) the same as lived in Quaternary times, as large as any living; a Mastodon, but much smaller than the great mastodon of later times; and a large number of species of the Horse and Camel families, besides other families of Ungulates, Carnivores, Rodents, etc., as shown in the accompanying schedule. Among the Pliocene horses was one (*Protohippus parvulus*), discovered by Marsh in the Upper Pliocene of Nebraska, only two feet high. "The large number of camels and horses gives a decided Oriental character to the fauna" (Dana). Both the horse and the camel seem to have originated on this, instead of on the Eastern, continent; at least the several steps of their derivation are more abundant and distinct here.

Rhinoceros.
Elephant.
Mastodon.
Three of the Camel family.
Five of the Horse "
Oreodon.
Deer.
Fox.
Wolf.
Tiger.
Beaver.
Porcupine.

Some General Observations on the Tertiary Mammalian Fauna.—1. Lartet has shown that the *brain-cavity* of some of the Tertiary animals is decidedly *smaller* relatively than that of their living congeners. Marsh has, moreover, traced a gradual increase in the relative size of the brain from the earliest Eocene to the present time. The brain of the *Coryphodon*, Lower Eocene, is not only extremely small in proportion to the size of the animal, but the higher portion of the brain—the cerebral lobes—is very small in proportion to the cerebellum. The brain of the Middle Eocene Dinoceras is only about one-eighth the size of a living Rhinoceros of equal bulk. The brain of the Miocene Brontothere is larger than that of the Eocene Dinoceras, but much smaller than that of

the Pliocene Mastodon of nearly the same size. Through the whole line

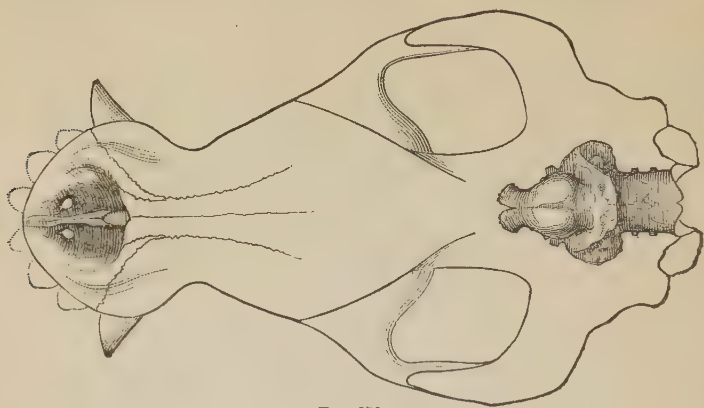


Fig. 850.

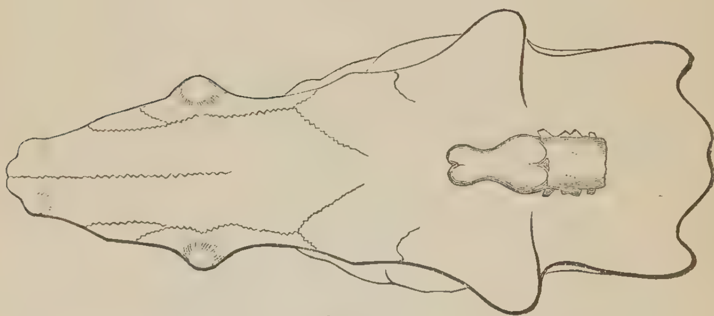


Fig. 851.

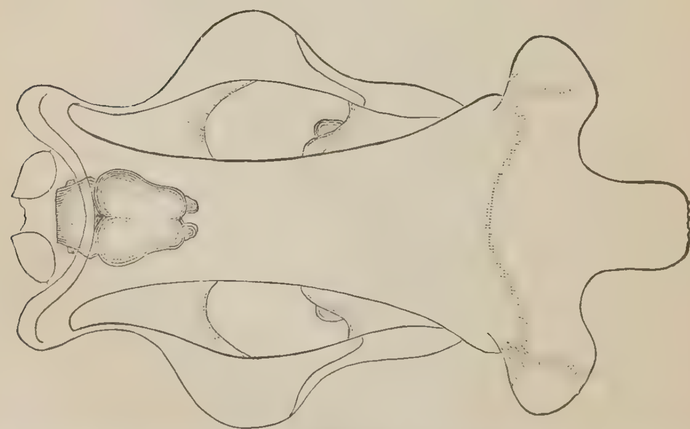


Fig. 852.

Figs. 850–852.—Brains of Coryphodon, Dinoceras, and Brontotherium, compared (after Marsh): 850. Coryphodon, Skull and Brain, × $\frac{1}{8}$. 851. Dinoceras, Skull and Brain, × $\frac{1}{8}$. 852. Brontotherium, Skull and Brain, × $\frac{1}{12}$.

of ancestry of the horse the gradually-increasing size of the brain may be traced step by step.

2. The animals of the Tertiary are nearly all *connecting types.*[1] As the Ungulates are the most largely represented, we can best illustrate the gradual differentiation of modern types in this order.

Cuvier divided all Ungulates into two orders, viz., *Pachyderms* and *Ruminants.* The Pachyderms are a heterogeneous order, but the Ruminants have been regarded as one of the most distinct of all mammalian orders. Their horns in pairs, their hoofs in pairs, absence of upper front-teeth, complex stomachs, and the habit of rumination, differentiated them widely from all other animals. But Prof. Owen showed that this distinction, so clear in zoölogy, was untenable in paleontology. He found, in studying extinct Ungulates, that another distinction, viz., foot-structure, was more fundamental and persistent. He therefore divided all Ungulates into *Perissodactyls* (odd-toed) and *Artiodactyls* (even-toed). A Perissodactyl may have five toes, as in the Coryphodon and the Elephant; or three toes, as in the Palæothere, the Rhinoceros, and the Tapir; or one toe, as in the Horse. The Artiodactyls always have their toes in pairs: there may be only two toes, as in Anoplothere and in Ruminants; or four, as in the Hog and the Hippopotamus. Owen, indeed, made the Elephant, Mastodon, etc., a distinct

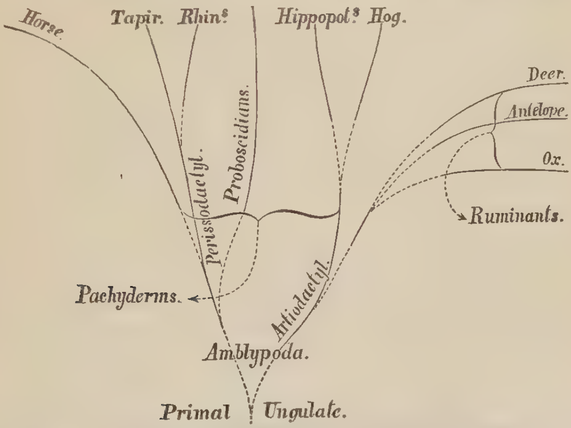


FIG. 853.—Diagram illustrating the Differentiation of the Different Families of Ungulates.

order, under the name of *Proboscidians*, but these are probably best regarded as a very distinct offshoot or sub-order of the Perissodactyls.

Now, in earliest Tertiary times the Perissodactyls and Artiodactyls already had diverged from a common stock, probably something like the Coryphodontidæ, although these were doubtless more nearly

[1] According to Cope, they may be divided into two generalized types, which he calls Bunotheria and Amblypoda. From the Bunotheria sprang by differentiation the Carnivores, the Insectivores, the Quadrumana, etc., while from the Amblypoda sprang the various families of Ungulates.

allied to the Perissodactyls. Each of the primary branches then divided and again divided, until the extreme branch in one direction became the Horse, and the extreme branch in the other direction the Ox. In the tree above we have attempted, in a general way, to represent the differentiation of the several orders of Ungulates. The Cuvierian orders, *Pachyderms* and *Ruminants*, are indicated by a vinculum. It is seen at a glance why, by studying living animals alone, the Ruminants seem so distinct.

Genesis of the Horse.—In conclusion, it will be interesting and instructive to run out one of these branches and show in more detail the genesis of one of the extreme forms. For this purpose we select the Horse, because it has been somewhat accurately traced by Huxley and by Marsh. About thirty-five or forty species of this family, ranging from the earliest Eocene to the Quaternary, are known in the United States. The steps of evolution may therefore be clearly traced.

In the lowest part of the Eocene basin (*Coryphodon beds*) of Green River is found the earliest known animal which is clearly referable to the horse family, viz., the recently-described *Eohippus* of Marsh. This animal had three toes on the hind-foot and four perfect, serviceable toes on the fore-foot; but, in addition, on the fore-foot an imperfect fifth metacarpal (splint), and possibly a corresponding rudimentary fifth toe (the thumb), like a dew-claw. Also, the two bones of the leg and fore-arm were yet *entirely distinct.* This animal was *no larger than a fox.* Next, in the *Middle Eocene* (Bridger beds), came the *Orohippus* of Marsh, an animal of similar size, and having similar structure, except that the rudimentary thumb or dew-claw is dropped, leaving only four toes on the fore-foot. Next came, in the *Lower Miocene*, the *Mesohippus*, in which the fourth toe has become a rudimentary and useless splint. Next came, still in the *Miocene*, the *Miohippus* of the United States and nearly-allied Anchithere of Europe, more horse-like than the preceding. The rudimentary fourth splint is now almost gone, and the middle hoof has become larger; nevertheless, the two side-hoofs are still serviceable. The two bones of the leg have also become united, though still quite distinct. This animal was about *the size of a sheep.* Next came, in the *Upper Miocene* and *Lower Pliocene*, the *Protohippus* of the United States and allied *Hipparion* of Europe, an animal still more horse-like than the preceding, both in structure and size. Every remnant of the fourth splint is now gone; the middle hoof has become still larger, and the two side-hoofs smaller and shorter, and no longer serviceable, except in marshy ground. It was about the *size of the ass.* Next came, in the *Pliocene*, the *Pliohippus*, almost a complete horse. The hoofs are reduced to one, but the splints of the two side-toes remain to attest the line of descent. It differs from the true horse in the skull, shape of the hoof, the less length of the molars, and some

other less important details. Last comes, in the *Quaternary*, the mod-

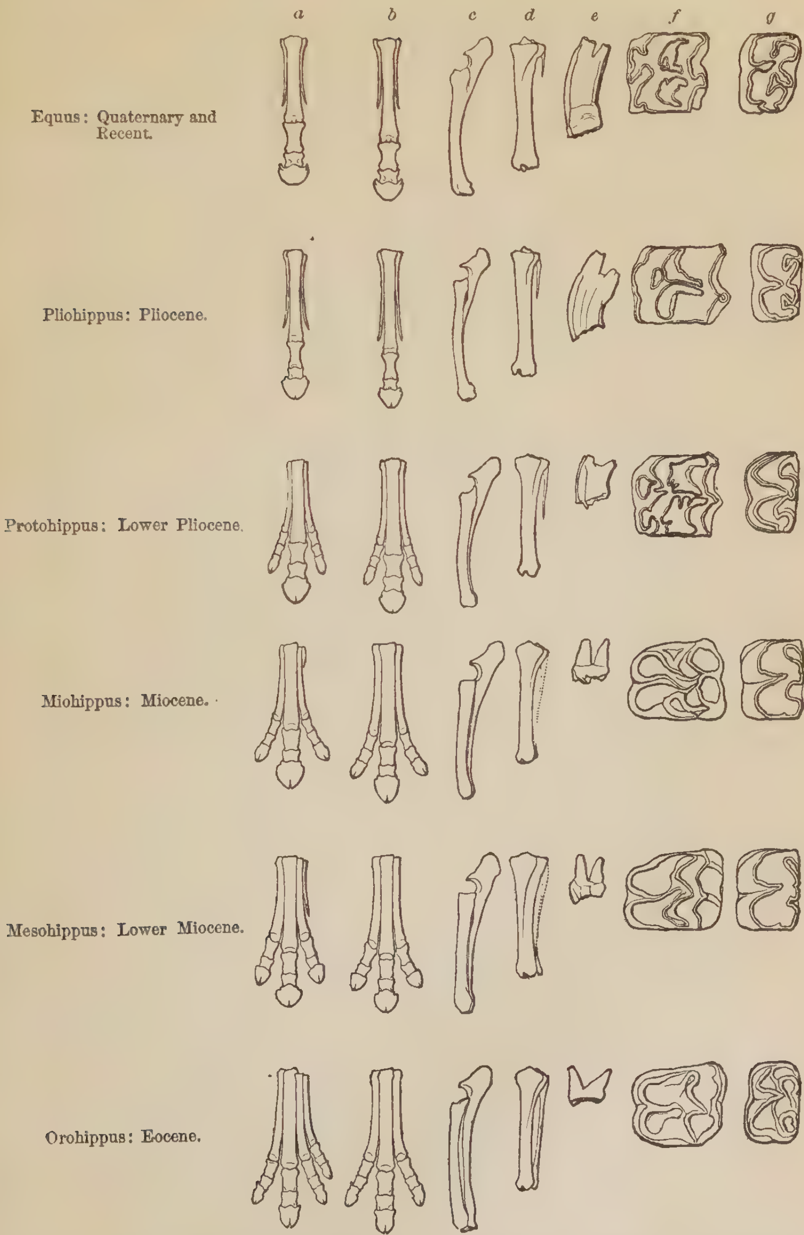


FIG. 854.—Diagram illustrating Gradual Changes in the Horse Family. Throughout *a* is fore-foot; *b*, hind-foot; *c*, fore-arm; *d*, shank; *e*, molar on side-view; *f* and *g*, grinding surface of upper and lower molars. (After Marsh.)

ern horse—*Equus*. The hoof becomes rounder, the splint-bones shorter, the molars longer, the second bone of the leg more rudimentary, and the evolutionary change is complete.

Similar gradual changes, becoming more and more horse-like, may be traced in the shape of the head and neck, and especially in the gradually-increasing length and complexity of structure of the grinding-teeth. All these changes are shown in Fig. 854, for which we are indebted to the kindness of Prof. Marsh. The Eohippus is omitted, as no figures of this have yet been published.

There can be no doubt that if we could trace the line of descent still farther back we would find a perfect five-toed ancestor. From this normal number of five, the toes have been successively dropped, according to a regular law: first, the thumb, No. 1; then the little finger, No. 5; then the index, No. 2; and last the ring-finger, No. 4; and the middle finger, No. 3, only remains. Nos. 2 and 4 are, however, usually dropped together.

A somewhat similar line of descent has been traced by Cope from the Miocene *Poëbrotherium* through the Pliocene *Procamelus* to the modern camel. It is remarkable that both the horse and the camel seem to have originated on this continent.

From the earliest and most generalized types, therefore, to the present specialized types, the principal changes have been, first, from plantigrade to digitigrade; second, from short-footed digitigrade to long-footed digitigrade, i. e., *increasing elevation of the heel;* third, from five toes to one toe in the Horse, or two toes in Ruminants; and, fourth, from simple omnivorous molars to the complex herbivorous millstones of the Horse and the Ox.

The change from plantigrade to digitigrade, with increasing elevation of the heel, when taken in connection with increasing size of the brain, and therefore presumably with increasing brain-power, shows a gradual improvement of structure adapted for speed and activity, and a *pari-passu* increase of nervous and muscular energy, necessary to work the improved structure.

3. Not only does the mammalian fauna of the Miocene differ completely from that of the Eocene, which precedes, and from the Pliocene, which succeeds it, but there seem to have been at least two distinct Eocene and two distinct Miocene faunæ. Thus there have been many complete changes in the mammalian fauna in Tertiary times.

General Observations on the Tertiary Period.

We have already seen (p. 472) that during Cretaceous times a wide sea, occupying the position of the Western Plains and Plateau region, divided America into two continents, an Eastern and a Western. We have also seen (p. 497) that at the end of the Cretaceous this sea was

obliterated by continental upheaval, and the continent became one. During the Eocene, the eastern portion of the place formerly occupied by this sea was probably dry land, but in the Plateau region there were great fresh-water lakes, one north of the Uintah Mountains, Green River basin, and one south of the same, and possibly one in Oregon. There were possibly others yet unknown. At the end of the Eocene, there was a *rise* in the Plateau region, which drained the Eocene lakes, and a corresponding *depression* in the Plains region on the one side, and the Basin region on the other, not sufficient to form a sea again, but sufficient to form great Miocene lakes there. At the end of the Miocene occurred the greatest event of the Tertiary period, one of the greatest in the history of the American Continent. At that time the sea-bottom off the then Pacific coast was crushed together into the most complicated folds (pp. 252, 267), and swollen up into the *Coast Chain*, and at the same time fissures were formed in the Cascade range, with the outpouring of the great lava-flood of the Northwest, already spoken of (p. 270). Coincidently with this there was a further *letting down* of the region of the Plains and of the Basin, and a consequent extension of the Pliocene lakes in these regions (attended probably with a further rise of the Plateau region). At the end of the Tertiary, these lakes were in their turn obliterated by the further upheaval of the continent, which inaugurated the Quaternary.

While this was going on in the *western* portion of the continent, on the southeastern and southern border the continent gained, by gradual rise, nearly all the area shaded as Tertiary. In this direction the continent was finished with the exception of the *larger portion of Florida* and the *sea-islands* and *alluvial flats*[1] about the shores of the Southern Atlantic and Gulf States. These belong to a still later period.

Thus we see that from the end of the Cretaceous to the end of the Tertiary there was a gradual upheaval of the whole western half of the continent, by which the axis, or lowest line, of the great interior continental basin was transferred more and more eastward to its present position, the Mississippi River. Probably correlative with this upheaval of the western half of the continent was the down-sinking of the mid-Pacific bottom, indicated by coral-reefs (p. 144). Also as a consequence of the same upheaval the erosive power of the rivers was greatly increased, and thus were formed those deep cañons in the regions (New Mexico, Colorado, and Arizona) where the elevation was greatest. Thus the *down-sinking* of the mid-Pacific bottom, the *bodily upheaval* of the Pacific side of the continent, and the *down-cutting* of the river-channels into those wonderful cañons, are closely connected with each other.

[1] In some places about the shores of the Gulf, for reasons which will be explained hereafter, the Quaternary deposits are considerably elevated above the sea-level.

SECTION 2.—QUATERNARY PERIOD.

Characteristics.—The chief characteristic of the Quaternary is that it is a period of great and widely-extended *oscillations* of the earth's crust in *high-latitude* regions, attended with *great changes of climate.* During this period the class of *mammals* seem to have *culminated.* During this period also *man* seems to have *appeared* on the scene. We do not call it the age of Man, however, because he had not yet established his reign. His appearance here is rather in accordance with the law of *anticipation.* As already stated, the invertebrate fauna was almost identical with that still living, but the mammalian fauna was almost wholly peculiar, differing both from the Tertiary which preceded and from the present which followed it.

Subdivisions.—The Quaternary period is divided into three epochs, viz.: I. *Glacial;* II. *Champlain;* III. *Terrace.* These epochs are characterized by the direction of the crust-movement, and of the *change of climate.* The *Glacial* epoch is characterized by an *upward* movement of the crust in high-latitude regions, until the continents in those regions stood 1,000 to 2,000 feet above their present height. Large portions of these regions seem to have been sheeted with ice, and an arctic rigor of climate extended far into now temperate regions.

The *Champlain* epoch, on the contrary, is characterized by a *downward* motion of land-surfaces in the same region until the sea stood relatively 500 to 1,000 feet above its present level, covering, of course, much that is now land-surface. It was, therefore, a period of *inland seas.* Coincident with this sinking was a *moderation* of climate, and a *melting of the ice.* It was, therefore, also a period of *great lakes* and *flooded rivers.* Over the inland seas and great lakes, loosened masses of *ice floated.* It was, therefore, also a period of *icebergs.*

The *Terrace* epoch is characterized by the gradual rising again to the present condition of the continents, and the establishment of the present condition of climate. It is, in fact, a *transition* to the *present era.*

Although we call these divisions *epochs*, yet we must not suppose that they are equal in length to the epochs of earlier times. As we approach the present time, and the number and interest of events increase, our divisions of time become shorter and shorter.

It is so difficult to separate these epochs sharply from each other in all countries, and to synchronize them, that it seems best to treat of the whole Quaternary period, taking up the epochs successively—first in Eastern North America, as the type or term of comparison, then of the same on the Pacific coast, and last of the same in Europe.

Quaternary Period in Eastern North America.

I. Glacial Epoch.

The Materials—Drift.—Strewed all over the northern part of North America, over hill and dale, over mountain and valley, covering alike, in places, all the country rock, Archæan, Palæozoic, Mesozoic, and Tertiary, to a depth of 30 to 300 feet, and thus largely concealing them from view, is found a *peculiar* surface soil or deposit. It consists of a heterogeneous mixture of clay, sand, gravel, pebbles, subangular stones of all sizes, unsorted, unstratified, unfossiliferous. The lowest part, lying in immediate contact with the subjacent country rock, is often a stiff clay inclosing subangular stones—i. e., rock-fragments with the corners and edges rubbed off. This we will call the "*Stony clay*" or "*Bowlder-clay.*" It is precisely like the *moraine profonde* of a glacier (p. 53). Over this is often found in places a looser material with *angular* stones, like the top moraine of glaciers. Lying on the surface of this drift-soil are found many bowl-

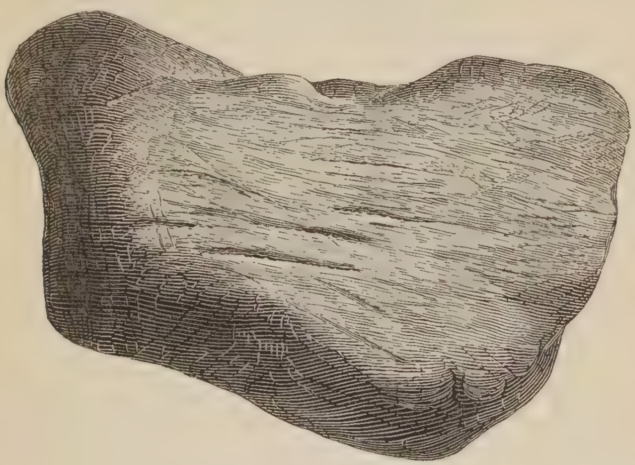


FIG. 855.—Subangular Stone (after Geikie).

ders of all sizes, often of huge dimensions, sometimes even 100 tons or more. The imbedded subangular stones are usually *marked with parallel scratches* (Fig. 855), and the large surface-bowlders are usually *angular and unscratched.* The depth of this material is greatest in the valleys and least on hill and mountain tops.

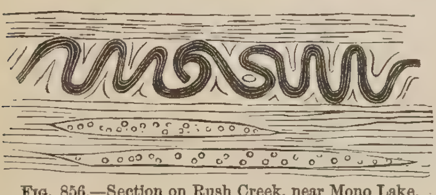


FIG. 856.—Section on Rush Creek, near Mono Lake, California.

It is difficult, nay, impossible, to give a description of this peculiar deposit, which will apply in all cases. Sometimes scattered about irregularly through the unstrati-

fied mass are portions which are roughly and *irregularly stratified*, the laminæ being often contorted in the most fantastic way (Figs. 856–858). Sometimes the true *stony clay* is covered with a more regularly *stratified* material, consisting of sand and gravel, apparently sub-

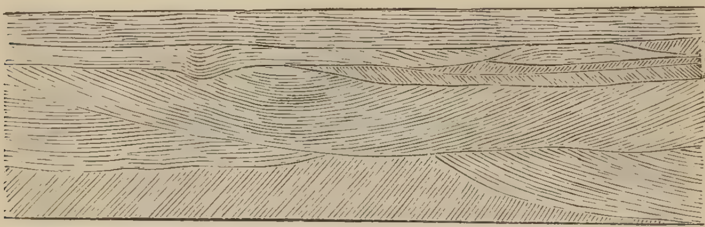


FIG. 857.—Section of Orange Sand, Mississippi (after Hilgard).

sequently deposited from water. This is particularly the case in the basin of the Mississippi, as, e. g., in Ohio, Illinois, and Iowa. It is probable, however, that this belongs to the next epoch, Champlain.

We have said that the deposit is peculiar. Nothing resembling it is found anywhere in tropical *or low-latitude countries.* In the South-

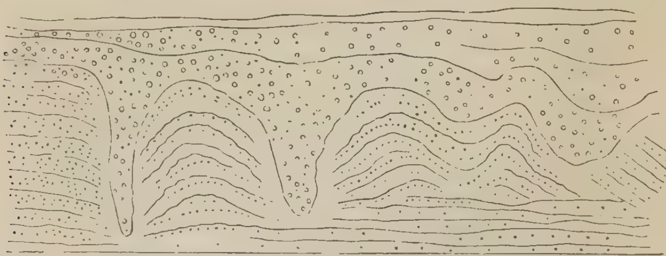


FIG. 858.—Section of Orange Sand, Mississippi (after Hilgard).

ern Atlantic States, for instance, the soil is mostly either the insoluble residue of rocks decomposed *in situ*, or else consists of neatly-stratified sands and clays.

Drift-material is *not* usually represented on geological maps, since it covers all kinds of country rock; or else the colors representing the

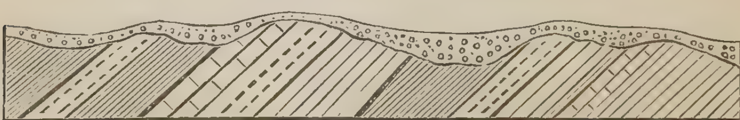


FIG. 859.—Outcropping—Eroded Country Rock overlaid by Drift.

various kinds and ages of country rock are simply *dotted* to indicate the presence of this surface-material. In sections, of course, it is easily represented, as in Fig. 859.

The Bowlders.—The most casual examination of the great bowlders

is sufficient in many cases to show that they do not belong to the country where they now lie, for they are of entirely different material from the country rock. For example, blocks of granite are found where there is no granite within many miles, blocks of sandstone on a country rock of limestone, or *vice versa*. In many cases it is easy to find the parent ledge from which these great fragments were torn, and thus to trace the *direction* of their transportation. From many observations of this kind it has been determined that in New England the bowlders have come usually from the *northwest*, in Ohio from the *north*, and in Iowa from the *northeast*. In other words, from the highlands of Canada and a ridge running thence northwestward (Archæan area), the general direction of travel has been southeast, south, and southwest. The distance carried may be only a few miles, or may be ten, fifty, one hundred, or even several hundred miles. In many cases they must have been carried across valleys 1,000 or 2,000 feet deep, and lodged high up on the mountain beyond. In many portions of New England and about Lake Superior the number of fragments, small and great, is so large as seriously to encumber the soil. Not only the large bowlders, however, but the whole mass of the material we have been describing, seem to have been shifted to a greater or less extent. It is for this reason that the material has been called *Drift*.

Surface-Rock underlying Drift.—On removing the drift-covering the underlying rock is everywhere *polished* and *planed* and *scored* with parallel lines, and *moutonné*, precisely like rocks over which a glacier has passed. We will, therefore, call this surface-appearance "*glaciation*." We reproduce here from page 52 the *roches moutonnées* of an ancient glacier in Colorado (Fig. 860). Examinations of the scorings show that they often pass straight up inclines for considerable distances, i. e., up one side of a hill, over the top, and down the other side. Their direction is uninfluenced by smaller inequalities of surface, though they are thus influenced by the *great valleys* and *mountain-ridges*.

The general direction of the scorings corresponds with that of transportation of the bowlders, showing that they are due to the same cause. Perfect soil on perfect sound rock always shows that the soil has not been formed *in situ*, but has been *shifted:* the *polishing*, *planing*, *scoring*, etc., of the rock show that the *agent* of the shifting has been *ice*.

Extent.—The general extent of these more conspicuous and characteristic phenomena, viz., the *glaciation*, the *stony clay*, and the *great bowlders*, is down to about 40° north latitude. The line of southern limit cuts the Atlantic coast about 40°, near New York; it then bends a little southward to 37° 30′ in Southern Illinois, and then turns a little northward again as it passes west, and may be traced northwestward nearly to Montana, and reappears on the Pacific slope in the southern portion of British Columbia (Dawson). Stretching southward of this

general limit are *local* extensions, usually down valleys. Beyond this the characteristic phenomena mentioned above are not found, but in the valley of the Mississippi, and on each side to a considerable distance, a superficial gravel and pebble deposit, containing northern

FIG. 860.—Roches Moutonnées of an Ancient Glacier, Colorado (after Hayden).

bowlders—called by Prof. Hilgard "Orange Sand"—extends to the shores of the Gulf. This deposit, however, probably belongs to the early Champlain epoch.

Marine Deposits.—Along the northern Atlantic coasts we find no marine deposits of this time, for the obvious reason that the continent, in that part, was then more elevated than now; whatever marine deposits were then formed are now covered by the sea. But along the Southern Atlantic States, coast-deposits of the ordinary kind seem to have been made continuously, and are still exposed. This shows that the peculiar and violent phenomena of the North did not reach so far, and therefore the epochs of the Quarternary period are undistinguishable there. The formation of the Peninsula and Keys of Florida, already explained (p. 149), probably belongs to the Quaternary and the present.

Theory of the Origin of the Drift.

When the phenomena of the Drift were first observed, they were supposed to indicate the agency of powerful currents, such as could be produced only by the most violent and instantaneous convulsions. A sudden upheaval of the ocean-bed in northern regions was supposed to have precipitated the sea upon the land, as a huge *wave of trans-*

lation, which swept from north toward the south, carrying death and ruin in its course. Hence the deposit was often called *Diluvium* (deluge-deposit). *Now*, however, they are universally ascribed to the agency of *ice* acting *slowly* through great periods of time. Hence the name *Glacial epoch.*

As to the *manner* in which the ice acted, however, opinions have been more or less divided, some attributing the phenomena to the agency of land-ice—*glaciers*—others to that of drifting *icebergs*. According to the one, the land during this epoch was greatly raised and covered with glaciers; according to the other, the same area was sunk several thousand feet and swept by drifting icebergs, carried southward by currents, and dropping their load of earth and stones. The one is called the *glacier* theory, the other the *iceberg* theory.

It is probable that *both* these agencies were at work, either at the same time or consecutively; but the decided tendency of science is toward the recognition of glaciers as the principal agent during this *earliest* epoch of the Quaternary. The more the phenomena are studied, and the more glaciers are studied, especially in polar regions, the larger is the share attributed to this agency. We will not discuss this question, but simply give the present condition of science on the subject.

Statement of the most Probable View.—The most probable view for America, and also for other countries, is, that the Drift, or at least the most characteristic phenomena of the Drift, viz., the *glaciation*, the *unsorted bowlder-clay*, and in many cases also the great *traveled bowlders*, are due to the action of *glaciers*. They are therefore a *land-deposit*, and not a sub-aqueous deposit. For general proof of this, let any one study the phenomena of *living* glaciers, in the Alps and elsewhere; then let him study the appearances left by the *recently dead* glaciers of the Sierra; and then let him study the phenomena of the Drift, especially the stony clay and the underlying glaciated surfaces. It will be impossible for him to come to any other conclusion than that the same agent has been at work in all these. In some cases, viz., in the valley-extensions of the Drift area, still more conclusive evidence is found in the existence of distinct *terminal moraines*.

Objections answered.—Many objections have been brought against this view, which may be compendiously stated as follows: 1. In glacial regions, like Switzerland, the Himalayas, etc., the glaciers run in *all directions;* but the Drift was carried over wide areas, in a *general direction.* Such a general direction is easily accounted for by the action of icebergs carried by marine currents. 2. The agent of the Drift seems to have been often uninfluenced by the direction of valleys and ridges even of considerable size; thus, for instance, bowlders are carried across valleys 500 or 1,000 feet deep, and lodged as high up on the

mountain-slope on the other side. This is perfectly consistent with the action of icebergs drifting over an uneven sea-bottom, but inconsistent with our usual notions of glacial action. 3. The great distance carried, sometimes one hundred miles or more, is precisely what we might expect of icebergs, but difficult to reconcile with our usual notions of glaciers. 4. Alpine glaciers will not move on a slope of less than 2° or 3°, but such a slope, carried several hundred miles, would produce an *incredible elevation of land.* A slope of $2\frac{1}{2}°$ for 200 miles would produce an elevation of nearly nine miles!

These were unanswerable objections so long as our ideas of glaciers were confined to those of temperate climates; but they all find their complete answer in the phenomena of the *polar ice-sheet.* Greenland is 1,200 miles long and 400 or 500 miles wide. This whole area of over a half-million of square miles is covered 3,000 feet deep with ice. This ice-mantle moves *en masse* seaward, moulding itself on the surface inequalities of the country, and moulding that surface beneath itself, producing *universal* glaciation, and only separating into distinct glaciers at its margin. In *antarctic* regions the general ice-sheet is even still more extensive and thick. Now, it is to such an ice-mantle that the Drift is to be ascribed, for it moves *irrespective of smaller valleys*, in *one general direction* over great areas, to *great distances*, and over a slope of only 1° or even $\frac{1}{2}°$.

Probable Condition during Glacial Times in America.—During Glacial times the Archæan region of Canada seems to have been elevated 1,000 to 2,000 feet above its present level, and covered with a general ice-mantle 3,000 feet to 6,000 feet thick. This ice-sheet moved with slow glacier motion southeastward, southward, and southwestward, over New England, New York, Ohio, Illinois, Iowa, etc., regardless of smaller valleys, glaciating the whole surface, and gouging out lakes in its course. Northward the ice-sheet probably extended to the poles; it was an extension of the *polar ice-cap*, but its southern limit was about 38° to 40° north latitude. The Colorado and other lofty ranges of the Rocky Mountain system were ice-covered, and great glaciers ran down their flanks. From its southern margin the ice-sheet stretched out icy fingers, as separate glaciers, down some of the principal valleys. For example: one great extension stretched southward as the *Hudson River glacier*, and its bed may still be traced far out to sea. Another was the *Susquehanna glacier*. Those along the eastern coast ran into the sea and produced icebergs; but westward over Ohio, Illinois, etc., where the glaciers, as well as the ice-sheet itself, did not run into the sea, these separate glaciers must have produced *terminal moraines;* but these have been mostly washed away by the floods of the Champlain epoch. Along the eastern slopes of the Colorado mountains the evidences of these separate glaciers are very abundant, and their lateral

and terminal moraines very distinct (Fig. 861). Some evidences of former glaciers have also been detected in the mountains of Virginia.[1]

It is probable that in the valley of the Mississippi the northern elevation extended even to the shores of the Gulf. Prof. Hilgard finds the evidence of this in the *Orange sand* which belongs to this epoch,

FIG. 861.—Moraines of Grape Creek, Sangre del Cristo Mountains, Colorado (after Stevenson).

or the beginning of the Champlain, and which indicates *torrential currents*, and must have been therefore deposited above sea-level, and yet in the region of the Mississippi Delta is now several hundred (400) feet below that level. The evidence is made still more conclusive by the discovery above the Orange sand of a stump-layer, or old forest-ground, also several hundred feet below present tide-level.

Terminal Moraine of the Ice-sheet.—There is much evidence to show that the ice-sheet, after beginning to retreat, again advanced or at least paused in its retreat. The limit of this second and more recent advance is marked by a very distinct moraine of irregular, deeply lobed outline, but nearly continuous from British America, a little to the north of Montana on the extreme northwest, through Dakota and Minnesota, and thence around the great lakes, where it is most irregular, and so eastward and northeastward to Long Island and Cape Cod. The discovery of this moraine, which we owe chiefly to Chamber-

[1] *American Journal of Science*, vol. vi., p. 371 (Stevens).

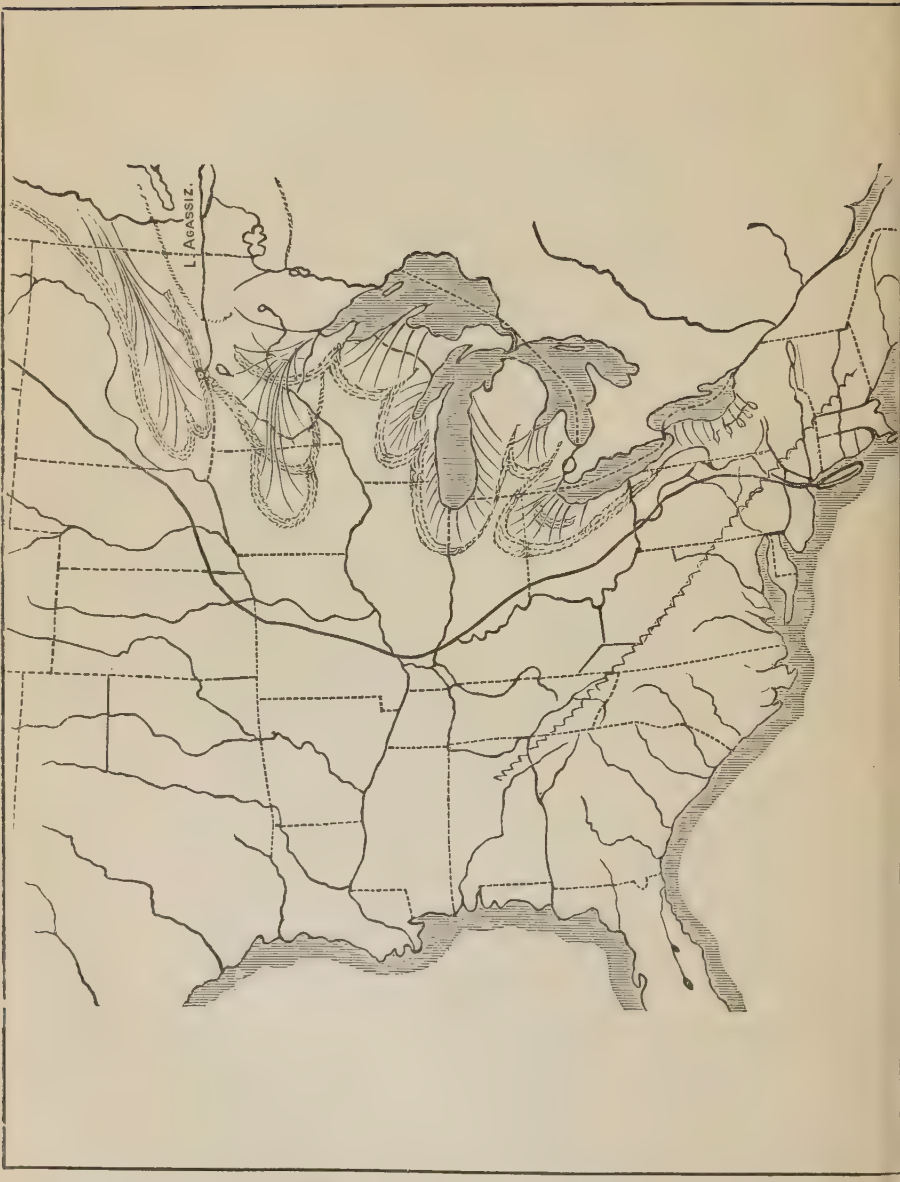


FIG. 861a.—Map showing the limit of the Drift and the Ice-Sheet Moraine, and position of Lake Agassiz. Limit of Northern Drift represented by heavy line from Long Island to Minnesota. Ice-Sheet Moraine represented by triple dotted line.

lin and Upham,[1] must be regarded as completely demonstrating the existence of the ice-sheet. Some fragments of the moraine of the ice-sheet at the limit of its greatest extension have also been found, but these are very imperfect. In the map, Fig. 861a, we give the limit of the northern drift—the probable outline of the ice-sheet at the time of its greatest extension—and also the outline of the moraine formed by its second advance.

II. Champlain Epoch.

During the Glacial epoch, as just seen, the whole northern portion of the continent was elevated 1,000 to 2,000 feet above the present condition; the polar ice-cap had advanced southward to 40° latitude, with still farther southward projections favored by local conditions; and an arctic rigor of climate prevailed over the United States even to the shores of the Gulf. At the end of this epoch an opposite or downward movement of land-surface over the same region commenced, and continued until a depression of 500 to 1,000 feet below the present level was attained. This downward movement marks the beginning of the *Champlain epoch.* As a necessary consequence, large portions of the now land were submerged; it was therefore a time of *inland seas.* Another result, or at least a concomitant, was a moderation of the climate, a melting of the glaciers and a retreat of the margin of the ice-cap northward. It was therefore a time of *flooded lakes and rivers.* Lastly, over these inland seas and great lakes loosened masses of ice floated as icebergs. It was therefore preëminently a time of *iceberg* action.

Evidences of Subsidence.—The evidences of the condition of things described above are found in old *sea-margins,* old *lake-margins,* old *river-terraces,* and old *flood-plain deposits.*

Sea-Margins.—Old sea-margins, containing shells and other remains of living species, are found all along the Northern Atlantic coast, becoming higher as we pass northward. In Southern New England the highest beaches are 40 to 50 feet; about Boston they are 75 to 100 feet; in Maine they are 200 feet and upward; on the Gulf of St. Lawrence they are 470 feet; in Labrador 500 feet. In arctic regions they are in some places 1,000 feet (Dana). The beaches may be traced up both sides of the St. Lawrence River, and thence around *Lake Champlain,* where the highest is 393 feet above tide-level.[2] Upon the beaches about Lake Champlain have been found abundance of *marine* shells, and also the skeleton of a *stranded whale.* Evidently there was here a great inland sea connected with the ocean through the Gulf of

[1] "Transactions of the Wisconsin Academy of Science," 1879; "Geological Survey of Minnesota," 1880.

[2] Dana, "Manual," p. 550.

St. Lawrence; and over this sea icebergs must have floated. This condition of things has given name to the epoch. In the subsequent reëlevation of the continent, this *salt lake* (as it must have been at first) was gradually rinsed out and freshened by river-water discharged through the lake and into the St. Lawrence River, as already explained on a previous page (p. 74).

Flooded Lakes.—All the lakes in the region affected by drift show unmistakable evidences of a far more extended and higher condition of the waters than now exists. About all these lakes is found a succession of terraces or old lake-margins. The highest of these marks the highest water-level, and is the *oldest;* the lower ones mark successive steps in the *draining* away or *drying* away of the waters.

For example, about Lake Ontario successive margins are found up to 500 feet above the present lake-level; about Lake Erie, up to 250 feet; about Lake Superior, up to 330 feet; and similar margins are found about Lakes Michigan and Huron. There can be no doubt that at this time these lakes ran together to form an *immense sheet of fresh water*, covering the larger portion of Ohio, which, according to Newberry,[1] drained southward into the Ohio and Mississippi Rivers, and on which floated many icebergs loosened from the Canadian glaciers, and dropping earth and bowlders over Ohio. Hilgard[2] thinks that the bursting of this great lake over a barrier across Southern Ohio and Illinois, discharging its waters southward, carried the Orange sand over that region.

G. M. Dawson[3] finds abundant evidence of a prodigious lake or sea in British America, extending from the Laurentian axis to the Rocky Mountains (doubtless connected with the lake previously mentioned), into which ran glaciers from the Laurentian axis on the one side, and the Rocky Mountains on the other, forming icebergs, which dropped their *débris* over the whole area.

The same ancient lake, though possibly in a later condition, had been previously discovered and figured by General (then Lieutenant) Warren,[4] who traced its outlet through the Minnesota into the Mississippi River. Recent investigations by Upham[5] have entirely confirmed the neglected results of General Warren, and the ancient lake has been named by him Lake Agassiz, in honor of the great champion of land-ice as the cause of the drift. According to Upham, this great lake was formed by the accumulation of the waters of the melting

[1] Newberry, "Surface Geology."

[2] *American Journal of Science and Arts*, December, 1871.

[3] *Quarterly Journal of the Geological Society*, vol. xxxi., pp. 620, *et seq.*, and "Geology of the Forty-ninth Parallel," chaps. ix., x.

[4] *American Journal of Science*, vol. xvi., No. 417, 1878.

[5] "Geological Survey of Minnesota," 1879.

ice-sheet on ground which sloped northward, but dammed by the foot of the retiring ice. As soon as the retiring ice-sheet passed the mouth of the Nelson River, the drainage followed its natural course northward through that river into Hudson Bay. The terraces traced by Upham indicate a lake two-thirds as large as Lake Superior (Fig. 861a).

Both the elevation of the previous epoch and the subsidence of this seem to have been *greater along the axis of the continent, the valley of the Mississippi, than on the coasts.* Hilgard finds evidence in the Orange-sand deposit, and in the thickness of the subsequent Champlain deposit, of an elevation of 450 feet above the present level, and a depression of 450 feet (for this is the maximum elevation of the Champlain deposit above the same level), or an oscillation of 900 feet, in Louisiana. Farther north it is probably much greater.

River Terraces and Old Flood-Plain Deposits.—Nearly all the rivers in the eastern portion of the continent, over the Drift region, are bordered with high *terraces*, which have been cut wholly out of an old flood-plain deposit belonging to the Champlain epoch. In fact, these rivers show first an elevation, then a depression, and finally a partial reëlevation; in other words, all the oscillations of the Quaternary period are recorded by them.

An examination of the rivers north of the fortieth parallel shows: 1. An *old river-bed* far deeper and broader than the present; 2. This deep and broad river-bed is filled up, often several hundred feet deep, by *old river-deposit;* 3. Into this old river-deposit the shrunken stream is again cutting, but is still far above the bottom of the old river-bed. This cutting into the old river-deposit produces bluffs and terraces on each side. It is evident that the great river-bed was gouged out during the Glacial epoch; the filling up took place during the Champlain, and the cutting and terracing during the Terrace epoch.

Fig. 862 is an ideal section across a river-bed in the Drift region, in which *b b* is the old river-bed, scooped out during the epoch of elevation; the dotted line represents the highest level to which the old river-deposit accumulated, and the shaded portion that part of such

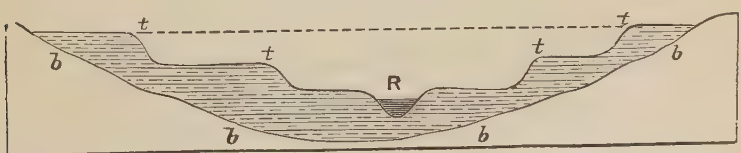


FIG. 862.—Ideal Section across a River-bed in Drift Region: *b b b*, old river-bed; *R*, the present river; *t t*, upper or older terraces; *t′ t′*, lower terraces.

deposit which still remains. The upper terraces, *t t*, are of course the oldest, the lower ones being made as the shrunken stream cut deeper and deeper.

These phenomena are shown in all the river-beds of the Drift region, but especially by those of the Mississippi basin. Sometimes there is only one terrace or bluff; sometimes there are several, on each side. The Connecticut River is a good example of the latter, the Mississippi River of the former.

The Connecticut River is bordered on each side by a succession of terraces rising one above and beyond the other, composed wholly of old river-deposit. Beyond this, of course, is the country rock of Jura-Trias sandstone, covered more or less with drift.

The *Mississippi River* is bordered on each side by its present flood-plain deposit, or river-swamps. This, as already said (p. 23), extends from the mouth of the Ohio River to the head of the delta, a distance of 800 miles, and has an average width of 20 miles. This, its present flood-plain deposit, is limited on the eastern side by bluffs in some places 200 to 400 feet high, composed of Tertiary strata, capped with an old river-silt, or Loëss, 50 to 70 feet thick, and this, again, covered by a yellow loam, which extends beyond the limits of the Loëss. A layer of Orange sand separates the Loëss from the Tertiary. Patches of the Loëss or *bluff-deposit* are found also on the western side, showing that the *old* flood-plain extended beyond the present flood-plain on both sides; but on the west side it has been mostly removed by subsequent erosion. Also similar deposits, often of great extent, form banks on each side of all the great tributaries of the Mississippi. *Beneath the present river swamp-deposit is found*, by borings, a deposit belonging, like the Loëss, to the Champlain epoch, but to an earliei period, probably an estuary deposit, and called by Hilgard "*Port Hudson*," varying in thickness from 30 feet at Memphis to several hundred feet in the delta. Beneath this is first the Orange sand and then the Tertiary.

All these facts are represented in the ideal section of the river and the strata in its vicinity, given below, constructed from the investiga-

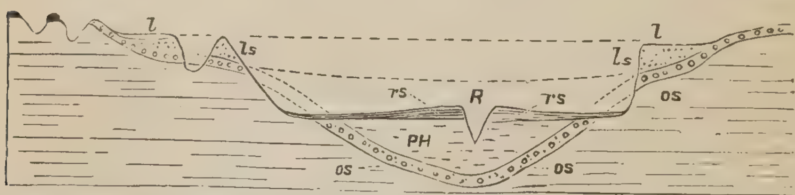


FIG. 863.—Ideal Section across Mississippi below Vicksburg: *OS*, Orange sand; *PH*, Port Hudson, estuary deposit. Champlain; *ls*, Loëss or old flood-plain deposit, Champlain; *l*, loam covering the Loëss, but more extensive; *rs*, river-swamp deposit, modern.

tions of Prof. Hilgard. It is evident that a great trough was hollowed out in the Tertiary strata during the Glacial epoch, filled with deposit to the level *l l* during the Champlain, and again partly cut out during the Terrace.

The cause of the flooded condition of the rivers and lakes was partly the depression of the land, by which the sea entered into the old glacial beds, forming estuaries ; partly the smaller angle of slope of the rivers, by reason of which the waters in their lower parts ran off less rapidly, and therefore were more swollen, and therefore also deposited more sediment ; and partly the greater abundance of the water-supply, from the melting of the glaciers.

III. Terrace Epoch.

At the end of the epoch of subsidence, when the condition of sea and lakes and rivers was what we have described, there commenced a movement again in an opposite direction, by which the lands were slowly brought upward to their present condition—a condition, however, far less elevated than during the Glacial epoch.

Evidences.—Sea.—The reëlevation was not perfectly steady and uniform, but stopped, from time to time, sufficiently long for the sea to make distinct beaches. Below the highest beach, which marks the maximum depression of the Champlain epoch, and which has already been described, several other beaches are traceable, which evidently mark the successive steps of reëlevation.

Lakes.—Also, the reëlevation of the land would bring down the level of the *lakes*, partly by change of climate diminishing the water-supply, and partly by increasing the slope, and thereby increasing the erosive power, of the discharge-rivers, and thus draining off the lake-waters. This is well shown on the Canadian lakes, where, in addition to the highest terrace, already mentioned, which marks the highest flood-level of the Champlain epoch, are found several lower terraces, which mark the successive stages of the subsequent depression of the lake-surface. These distinct beaches would seem to indicate that the *rate* of draining away and letting down of the water was not uniform, but had periods of greater and periods of less rapidity.

Rivers.—It is hardly necessary to say that the reëlevation would lay bare the old flood and estuary deposits of the rivers, and the rivers would immediately commence cutting into these deposits, forming terraces and bluffs, in number and height depending upon the depth of the cutting. The Connecticut River has made many of these terraces, the highest, of course, being the oldest. The Mississippi has apparently made but one, but this one is very high (Fig. 863). The highest point of this Champlain deposit, according to Hilgard, is at least 450 feet above tide-level, showing a reëlevation and a cutting to that extent during the Terrace epoch.

History of the Mississippi River.—It may be interesting to stop a moment, and trace, briefly, the history of this great river. During the

Cretaceous period, the Ohio probably ran into the embayment of the Gulf, represented in Fig. 728 (p. 472); but the Mississippi did not yet exist. The drainage of all that part of the continent was, doubtless, into the great Cretaceous inter-continental sea. At the beginning of the *Tertiary period*, the Mississippi probably commenced to run into the Tertiary embayment, shown in Fig. 790 (p. 501). The Red and Arkansas, if they then existed, were not tributaries, but separate rivers, emptying into the same embayment. The Ohio was almost, if not quite, a separate river also. During the *Glacial epoch*, the whole embayment of the Gulf was abolished by elevation. This is clearly demonstrated by the torrential pebble-deposit (Orange sand), and by the stump-layer (old forest-ground), found by Hilgard beneath the Port Hudson (Champlain) deposit, on the shores of the Gulf. During the *same epoch*, by reason of this elevation, the great trough, represented in Fig. 863, was scooped out of the Tertiary strata, 200 to 500 feet deep, either by a tongue-like extension of the northern ice-sheet, or else, more probably, by the erosive power of water, favored by the greater slope of the country southward at that time, and also by the greater water-supply. During the *Champlain epoch*, by subsidence this great trough became an arm of the Gulf, or an estuary, fifty to one hundred miles wide, and reaching up to the mouth of the Ohio, with extensions up the tributaries; and this estuary became filled, 200 to 500 feet deep, with sediments. This deposit was at first estuarian (Port Hudson), and afterward river-silt (Loess). At the same time the Mississippi was connected with the great lakes then greatly enlarged, and with Lake Winnipeg, then also greatly enlarged, as Lake Agassiz. During the *Terrace epoch*, this silt was laid bare, and the river commenced, and continued to cut, until the bluffs became 200 to 400 feet high. Finally, during the *Recent epoch*, the river has again commenced *building up* by sedimentation, showing thus a slight depression again, or, at least, a *cessation*, of the re-elevation of the Terrace epoch. This up-building by sedimentation has continued up to the present moment, and the deposit (river-swamp and delta deposit) has reached, according to Hilgard, a thickness of forty to fifty feet. Thus the phenomena of the Mississippi distinctly separate the Terrace from the Recent epoch.

Quaternary Period on the Western Side of the Continent.

All the most characteristic phenomena of this period, such as *general glaciation*, *raised sea-margins*, *flooded lakes*, and *flooded rivers*, are abundant and conspicuous on the Pacific side of the continent. Especially are the evidences of *separate* ancient glaciers far more per-

fect than on the eastern coast, in fact as perfect as in any part of the world.

Glaciers.[1]—There seems no doubt that during the fullness of Glacial times the whole high Sierra region, as far as Southern California, was ice-sheeted. Whether this should be regarded as an extension of the northern ice-cap is perhaps doubtful. From the margins of this sheet stretched valley-extensions in the form of separate glaciers to the plains east and west. At the same time even the Coast Range was covered with perpetual snow, and glaciers ran down into the Bay of San Francisco.[2] The direction of motion, and therefore of transportation, was *mainly* eastward and westward from the crest, determined by the *mountain-slope;* but also *partly southward*, determined by *northern elevation*. The evidence of this condition of things is yet imperfect. It consists mainly in the general contour-forms of the surface of the whole higher or granite region of the Sierra—a rounded, billowy appearance, like *moutonné* rocks on a huge scale.

Following this ice-sheeted condition, we have in the same region the most perfect and abundant evidences of an epoch of great *separate glaciers*, and associated with these are evidences of *flooded lakes*, into which the glaciers ran and formed icebergs, and of *flooded rivers*, whose swollen currents carried away and redeposited the glacial *débris*. This time of great glaciers in California probably corresponds with the Champlain epoch.

It is impossible to describe all the great ancient glaciers whose tracks have been traced. They filled all the larger cañons, and their tributaries all the higher and smaller valleys and meadows. Their tracks are everywhere marked by glaciation and strewed bowlders, and their terminus at different times by a succession of terminal moraines and lakelets. We will mention three or four as examples:

1. During the epoch spoken of, a great glacier, receiving tributaries from Mount Hoffman, Cathedral Peaks, Mount Lyell and Mount Clark groups, filled *Yosemite Valley*, and passed down Merced Cañon. The evidences are clear everywhere, but especially in the upper valleys, where the ice-action lingered longest.

2. At the same time tributaries from Mount Dana, Mono Pass, and Mount Lyell, met at the Tuolumne meadows to form an immense glacier, which, overflowing its bounds a little below Soda Springs, sent a branch down the Tenaya Cañon to join the Yosemite glacier, while the main current flowed down the Tuolumne Cañon and through Hetch-

[1] For a fuller account of the glaciers of the Sierra, and the condition of things during the Glacial epoch, see *American Journal of Science*, vol. iii., p. 325, and vol. x., p. 26.

[2] Undoubted marks of ancient glaciers are found about Berkeley, 200 feet above the bay.

hetchy Valley. Knobs of granite, 500 to 800 feet high, standing in its pathway, were enveloped and swept over, and are now left round, and polished, and scored, in the most perfect manner. This glacier was at least forty miles long and 1,000 feet thick, for its stranded lateral moraine may be traced so high along the slopes of the bounding mountain.

3. The Sierra range on its western side slopes gradually for fifty or sixty miles; but on the eastern side it is very precipitous, so that the plains 5,000 to 7,000 feet below the crest are reached in two or three miles. In glacial times long and complicated Glaciers with many tributuaries occupied the western slope, while on the eastern slope innumerable short, simple glaciers flowed in parallel streams down the steep incline and out for several miles on the level plain, or even into the waters of Lake Mono. One of the largest of these took its rise in the snow-fields about Mono Pass, flowed down *Bloody Cañon*, and six to seven miles out on the plain, and evidently into the waters of Lake Mono, which was then far more extensive and higher than now. Parallel moraines, 300 feet high, formed by the dropping of glacial *débris* on each side of the icy tongue, as it ran out on the plain or on the bottom of the shallow lake, are very conspicuous, as are also the successive *terminal* moraines left in the subsequent retreat. Behind these moraines water has accumulated, forming lakelets.

4. In the fullness of Glacial times Lake Tahoe basin was wholly occupied by ice, which probably ran out upon the plains of the Basin region. But in the epoch of great glaciers, of which we are now speaking, its basin was filled with water, and to a somewhat higher level than at present; and into the lake ran many glaciers, whose tracks are still perfectly distinct. The lakelets and lake-like bay seen about the southern end of the great lake, and which form so conspicuous a feature of its scenery, were scooped out by these steeply-descending glaciers; and the long parallel *débris*-ridges bordering the lakelets, and stretching down to the shores of the great lake, have been deposited on each side of the glaciers as they ran out into the lake, doubtless to form icebergs.[1] (*See* Fig. 864).

During the *Terrace epoch* these great glaciers of the Sierra retreated, but not at uniform rate, leaving very distinct terminal moraines at the places where their points rested awhile, until they have mostly retired within the snow-fields which gave them birth. The feeble remains of some of them may still be found hidden away among the coolest and shadiest hollows of the high Sierra region.

Lake-Margins.—About all the great lakes there are terraces or other evidences of a higher and more extensive condition of their waters. About *Lake Mono* there are five or six very distinct terraces, the highest of which is 600 to 700 feet above the present lake-level. This

[1] *American Journal of Science*, vol. x., p. 126, 1875.

would carry the lake-waters to the base of the Sierra, and necessitate the flow of glaciers into them, and the formation of icebergs.

About *Great Salt Lake* successive terraces have been traced up to more than 900 feet above the present lake-level. At that time it is estimated to have contained 400 times its present volume of water; and there are some reasons for thinking that it probably once dis-

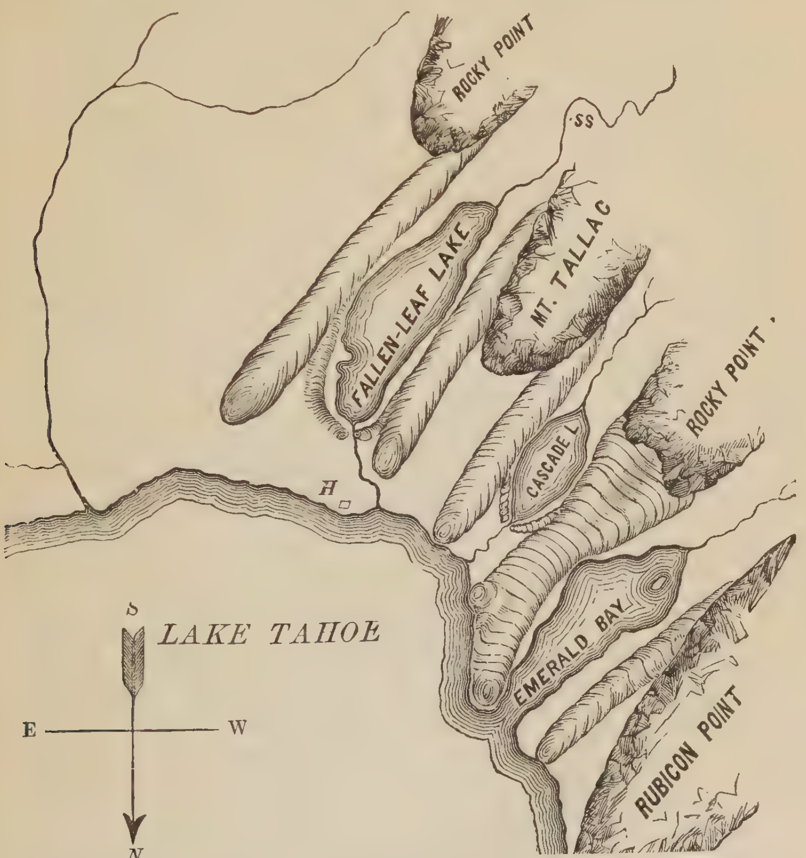


FIG. 864.—Diagram Map, showing the Southern End of Lake Tahoe with its Lakelets and Lateral Moraines.

charged into the Pacific through the Snake and Columbia Rivers, for the divide between the Salt Lake basin and the Columbia River is only about 600 feet above the present lake-level.[1] If so, it was then a *fresh*, or, at least, a *brackish-water lake*. About other salt lakes in this region the same phenomenon is observed. In fact, in all the Basin

[1] Dr. Blake, "Proceedings of California Academy of Science," vol. iv., p. 276.

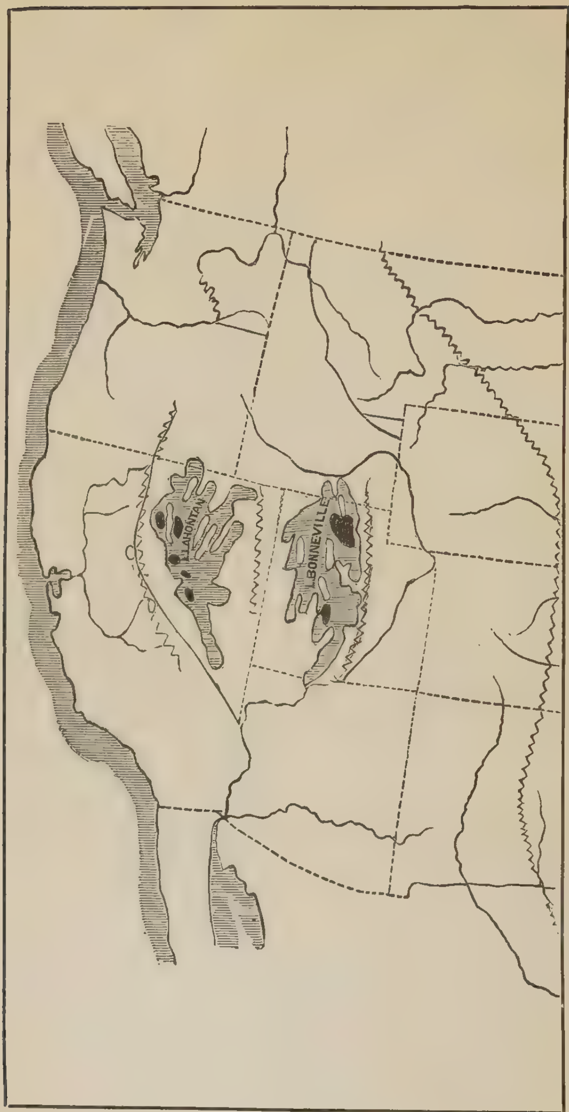


FIG. 864a.—Map showing Lake Bonneville and Lake Lahontan.

region, the valleys between the parallel ranges were then filled with water (Gilbert), forming two great lakes nearly as large as Lake Superior, one filling the Utah the other the Nevada Basin; the one named by Gilbert Lake Bonneville, the other by King Lake Lahontan, in honor of the early explorers of this region. In these great lakes

existing mountain ranges rose as islands. These quaternary lakes are represented in generalized outline in the map on page 544.

During the *Terrace epoch* these lakes were partly *drained* away, but still more *dried* away to lower and lower levels, marked now by successive terraces. For, if in the East the lakes were mostly *drained* away by change of *level*, in the West they were mostly *dried* away by change of *climate*. The salt and alkaline lakes now scattered all over this region are the isolated residues of these two great lakes.

Rivers.—The rivers, especially in California, mark very distinctly all the stages of the Quaternary. There are in many parts of California two systems of river-beds, an *old* and a *new*. The old belongs to the Tertiary; the new, to the Quaternary and present. The change took place during the oscillations of the Quaternary. The old river-system is substantially parallel to the present river-system, though in some places the one cuts across the other. It is probable, therefore, that there was but little change in the general direction of the slope, produced by the oscillations of this epoch. These old river-beds are filled with Drift-gravel, and often covered with lava-streams. They will be again referred to and described in connection with gold (p. 584). These Drift-gravels probably represent the beginning of the Glacial epoch, though Whitney thinks an earlier or Pliocene epoch. The present river-system sometimes cuts across, sometimes runs parallel to, the lava-filled beds of the old river-system, and the beds of the former have in their turn been eroded 2,000 to 3,000 feet in solid rock. In these also have been accumulated immense quantities of gravel and bowlder Drift, evidently brought down from the

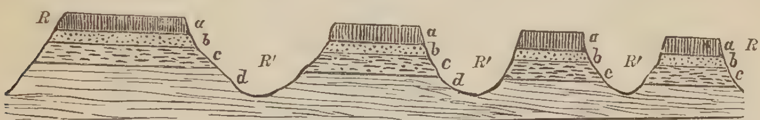


FIG. 865.—Lava-Stream cut through by Rivers: *a*, *a*, basalt; *b*, *b*, volcanic ashes; *c*, *c*, Tertiary; *d*, *d*, Cretaceous rocks; *R R*, direction of the old river-bed; *R′*, *R′*, sections of the present river-beds (from Whitney).

glacial moraines by the swollen rivers of the Champlain and early Terrace epochs. These facts are illustrated by Figs. 865 and 866, in which *R′* represents the present river-system, in Fig. 865, cutting across, and in Fig. 866 running parallel to, the old system *R*.

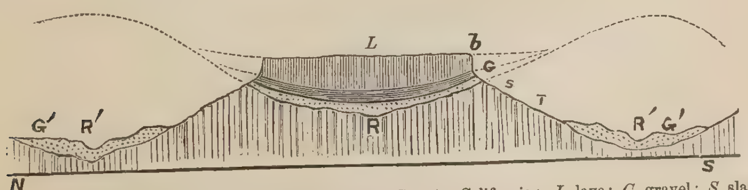


FIG. 866.—Section across Table Mountain, Tuolumne County, California: *L*, lava; *G*, gravel; *S*, slate; *R*, old river-bed; *R′*, present river-bed.

Although it is impossible to synchronize with certainty these events with the changes in the eastern portion of the continent, yet the order of sequence is evident; and that the greater part, if not all, occurred in the Quaternary, is also evident.

Seas.—The boldness of the whole Pacific coast, especially in high latitudes, indicates, as will be more fully shown hereafter (p. 560), a previous more elevated condition of the land-surface than now exists. Demonstrative evidence of the same is also found in elephant-bones recently discovered on the small island of Santa Rosa, which must then have been *connected with the mainland.*[1] This was during the *Glacial* epoch. Again, elevated terraces found in many places along the California coast belong undoubtedly to the *Champlain* epoch. At San

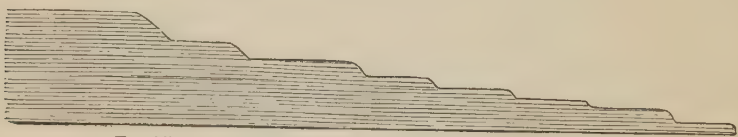


Fig. 867.—Sea-Terraces at San Pedro, California (after Davidson).

Pedro, Lieutenant Davidson finds ten of these, most of them well marked, rising one above another from sixty-five to 1,200 feet above present sea-level.[2] At that time the sea not only occupied the bay of San Francisco, but covered all the flat lands about the bay, including the valleys of Santa Clara, Napa, and Sonoma ; and thence extending inward, covered also the whole Sacramento and San Joaquin plains, forming thus an immense sound 300 miles long and fifty miles wide. The margins of this old sound are distinctly seen in the Upper Sacramento Valley. In *Oregon* Mr. Condon has traced an old sea-margin from the coast up the Columbia River to and beyond the Cascade range. At that time, according to him, the sea entered the Columbia as a great estuary, spread out over the Willamette Valley as a *great sound*, and thence up the river. *Puget Sound*, with its deep, narrow, complicated channels, was probably produced by subaërial erosion, at a time of greater *land-elevation.* Again, the complicated system of prairies which surrounds its southern end is evidence of former extension of the sound, and therefore of an epoch of subsidence, from which reëlevation has brought the waters to their present condition.

On the Thompson River, British Columbia, beautiful terraces are seen 50 to 500 feet above the present level of the river (Lord Milton).

The Quaternary Period in Europe.

In Europe the phenomena were more irregular, the oscillations more numerous, and perhaps more local, than in America. This is in

[1] "Proc. California Academy of Science," vol. v., p. 152. [2] Ibid., vol. v., p. 90.

accordance with the general difference in the geological history of the two continents. Again, in America elevation predominated ; in Europe, subsidence. Therefore, in America true glacial phenomena predominated ; in Europe, iceberg phenomena. Nevertheless, the general character of the phenomena was similar in the two countries. The most conspicuous and universal effects reach, in Europe, as far as about 50° north latitude.

1. Epoch of Elevation—First Glacial Epoch.—The Quaternary was inaugurated in Europe, as in America, by an epoch of elevation, when the northern portions of that continent stood 1,000 feet or more above

FIG. 868.—Map of Outline of Coast of Western Europe, if elevated 600 Feet (after Lyell).

its present level. The whole of Scandinavia, the whole of Scotland, and the northern and mountainous portions of England, were ice-sheeted

—the ice moving from these regions southwestward, southward, southeastward, and eastward, producing universal glaciation. The Baltic Sea, the North Sea, and a wide border about the British Isles, were then land, and swept over by glaciers. Above we give a map (Fig. 868), from Lyell, showing what would be the outline of Northwestern Europe, if raised only 600 feet.

Switzerland, at this time, though not ice-sheeted, developed glaciers on a prodigious scale. Some of these have been traced out with great care and skill. Especially has this been done for the *great Rhône glacier*, by Guyot. At that time a great glacier came down the valley of the Rhône, emerged on the plains, and filled the whole valley of Switzerland, fifty miles wide, between the Alps and the Jura, forming a great *mer de glace* 50 miles wide, 150 miles long, and 4,000 to 5,000[1] feet deep. A figure is given below of this great glacier. The dotted lines show the direction of motion as determined by bowlders left in the valley or stranded high up on the slopes of the Jura.

Fig. 869.—Map showing the Outline and Course of Flow of the Great Rhône Glacier (after Lyell).

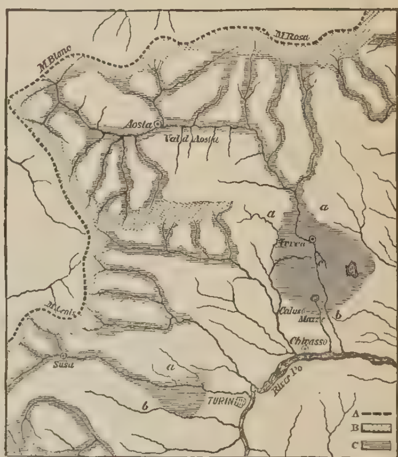


Fig. 870.—Map showing the Lines of *Débris* extending from the Alps into the Plains of the Po (after Lyell).

Lakes Geneva and Neufchâtel were probably scooped out by this great glacier.

At the same time, also, on the southern slopes of the Alps, long glaciers stretched out on the plains of Lombardy, as shown by the prodigious piles of *débris* (moraines) still left. Some of these moraines are 1,500 feet high. Fig. 870 is a map of these lines of *débris*.

Evidences of glaciers of this time are also found in the Vosges, in the Pyrenees, and other high mountains of Central Europe.

2. **Epoch of Submergence—Champlain.**—Following the epoch of elevation was an epoch of subsidence, during which the same regions

[1] "Archives des Sciences," vol. lviii., p. 159, 1877, and vol. iii., p. 228, 1880.

which were before most elevated became now most depressed. It is believed that in Scotland the land was at least 2,000 feet below the *present level.* By this depression a great part of Northern Europe was submerged, and Great Britain was reduced to an archipelago of small islets. Over the area thus submerged drifted icebergs loosened from the Scandinavian ice-field.

FIG. 871.—Map of the British Isles and Norway, if subsided 1,200 to 2,000 Feet (after Lyell). The lower shaded portion was not touched by Drift.

At the same time, partly by subsidence, and therefore slackened water-currents, and partly by moderated climate and melting of glaciers, there was a flooded condition of rivers and lakes in Middle Europe, France, Germany, and Switzerland. At the same time, also, the northern portion of Asia and the lake-region of that continent were submerged. The Caspian Sea, Lake Aral, and other lakes in that region, were probably then united into one great inland sea, connected either with the

Black Sea or the then greatly-extended Arctic Ocean, or with both.[1] Either at this time, or more probably during the Glacial epoch, the Desert of Sahara was submerged.

Evidences of this condition of things are found in old sea-margins, lake-margins, river-terraces, and flood-plain deposits.

3. Epoch of Reëlevation—Second Glacial Epoch—Terrace Epoch.—The period of submergence was followed, as in America, by another of reëlevation, as shown by the successive beaches and terraces on sea-shores, about lakes, and on rivers. But in Europe the reëlevation went much *beyond the present level*, and brought on a *second Glacial epoch*, not, indeed, equal to the first—not an ice-sheeted epoch—but a reign of great separate glaciers. During this time Great Britain was again connected with the continent.

4. Modern Epoch.—Afterward the continent again came down to its present condition, and thus inaugurated the Modern epoch. In Europe, therefore, the Terrace is more distinctly separated from the present epoch than in America.

Some General Results of Glacial Erosion.

1. Fiords.—We have seen that the phenomena of rivers, in the region affected by the Drift, show elevation, then subsidence, and then reëlevation to a less height than the first. The first elevation is shown in their deep, ancient beds; the subsidence, in the filling up of these with deposit; the reëlevation, in the cutting down into the deposit, and forming terraces. Now, all these changes are also shown in the phenomena of *fiords* (Dana).

It will be remembered (p. 35) that the Norway coast is wonderfully bold and deeply dissected, consisting of high, rocky headlands, separated by deep inlets running 50 to 100 miles into the country; and off shore there is a line of high, rocky isles, evidently the remnants of an old shore-line. These deep inlets are called in Norway *Fiords;* and the name is now used for all such deep inlets separating high headlands. The coast of Greenland has a precisely similar structure. It, also, consists of bold, rocky headlands, separated by fiords running far into the country; and off shore a line of rocky isles 2,000 feet high. In Greenland these fiords are now occupied by glacial extensions of the general ice-mantle. The same coast-structure is found on the western side in high latitudes. The coast of British America and Alaska is also bold and deeply dissected by fiords; and in Alaska these fiords are now occupied by great glaciers running down to the sea (Fig. 872).

Now, it seems certain that fiords are deeply-eroded valleys, which have become *half submerged;* and as glaciers are the most powerful of erosive agents, they are usually *half-submerged glacial valleys.* These

[1] *Nature*, vol. xiii., p. 74; *Natural History Magazine*, vol. xvii., p. 176; "Archives des Sciences," vol. liv., p. 427.

valleys can in most cases be traced as submarine troughs, far out to sea. In Greenland, for instance, the extension of these troughs, deep below the present sea-level and far out beyond the reach of the present glaciers, shows a former more elevated condition; and terraces and recent deposits up to 500 feet show a subsidence below, and a reëlevation to, the present level. Also, Puget Sound, as already stated, shows the same succession of changes.

All shores in northern regions are bold and rocky and deeply dissected, and have rocky islets off shore; in other words, are more or less

Fig. 872.—Ideal Section through a Fiord.

affected with *fiord-structure*. They have been elevated, glacially eroded, and subsided. It is probable that during the epoch of greatest elevation a *broad continental connection existed* between America and Asia, including the whole area between the Aleutian Isles and Behring Straits.

2. **Glacial Lakes.**—Lakes are found in all parts of the earth, and are doubtless due to different agencies, but there can be little doubt that most of those found in the Drift region are formed by glacial agency. The whole region which has been affected by glacial agency is thickly dotted over with lakes, while south of this region there is a comparative absence of them. In the glacial region of the Sierra Nevada, glacial lakes are evidently formed in two ways: They are either rock-basins scooped out by a glacier at some point of its path where the rock is softer, or where the angle of slope becomes suddenly less; or else they are formed by the damming up of waters behind the terminal moraines left by a retiring glacier. Both of these kinds are very abundant in the Sierra and other mountain regions. The former are usually high up the valleys, the latter somewhat lower down. The marshes and meadows so common in old glacial regions are also often traceable to the filling up of glacial lakes.[1]

Life of the Quaternary Period.

Plants and Invertebrates.—Remains of the life of the Quaternary, both animal and vegetable, are very numerous, and often very well pre-

[1] See Appendix.

served. Both the plants and the invertebrate animals are almost wholly identical with those now living on the earth. We will therefore dismiss these with one important remark: The plants and the marine shells show *an arctic climate in now temperate regions.* The species found are still living, but *living farther north.* There has been a *migration* of species *northward* since Glacial times.

Mammals.—But the *mammalian* fauna of the Quaternary is almost wholly peculiar. It differs greatly from the Tertiary fauna preceding, and the present fauna succeeding. The species are, moreover, very numerous, and many of them of extraordinary size; for it is the culmination of the mammalian age. It is necessary, therefore, to describe some of them, and the conditions under which they were preserved, and thus to realize in some degree the conditions under which they lived. We will take our first illustrations from Europe, because the remains are more numerous and have been more thoroughly studied there.

Mammalian remains of this time are found in Europe—1. In *caverns*, where in great numbers they have become *entombed;* 2. On *beaches and terraces*, where their floating carcasses have become *stranded;* 3. In *marshes and peat-bogs*, where, venturing in search of food, they have *mired* and perished; 4. In *ice-cliffs and frozen soils*, where they have been *hermetically sealed* and preserved to the present time.

1. Bone-Caverns.—The richest sources of Quaternary mammalian remains are undoubtedly *bone-caverns.* These occur in nearly all countries, often along the course of streams, but high above the present stream-level. Their formation and their filling are in some way connected with the floods of the Champlain epoch. They are rich in organic remains, to a degree which is almost incredible. One of the most striking peculiarities of these remains is, that they often consist of a *heterogeneous mixture of all kinds*, carnivorous and herbivorous, and *all sizes*, from the Elephant and Cave-bear on the one hand down to Rats and Weasels on the other; sometimes perfect, more often broken, mingled with earth and gravel, forming unstratified *bone-rubbish.* Another peculiarity of these deposits is that they are often covered and, as it were, sealed by a stalagmitic crust formed by subsequent drippings from the roof, and thus preserved against even the suspicion of disturbance to the present time. We give (p. 563) a section of the cave of Gailenreuth, with its bone-rubbish and stalagmitic crust.

Among the remains of Herbivores found in bone-caverns, the most remarkable are those of the Elephant, Rhinoceros, Hippopotamus, the great Irish Elk, besides Horses and Oxen. Among Carnivores are the Cave-bear (*Ursus spelæus*), larger than the Grizzly, the Cave-hyena,[1] the Cave-lion,[1] the Sabre-toothed Tiger (*Machairodus latidens*), with its

[1] These are supposed to be the same species as the African lion and hyena of the present day, but much larger.

sabre-like tusks, ten inches long, besides smaller animals of the same order. The remains of the larger Carnivora, especially the Cave-bear and the Cave-hyena, are the most abundant. The *bones of the smaller*

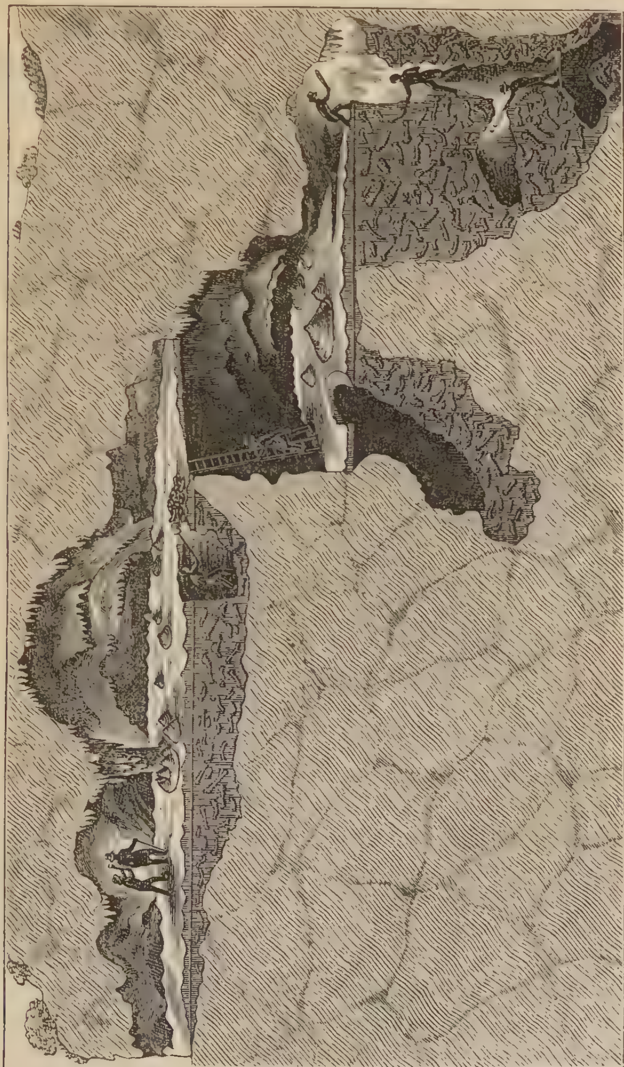


FIG. 873.—Vertical Section through Gailenreuth Cave, Franconia.

Herbivores bear the marks of teeth, as if they had been *gnawed*. The skeletons of the large Pachyderms are usually more perfect. In the Kirkdale Cave, England, the teeth and other parts of 300 individuals of the Cave-hyena were found. In the Gailenreuth Cave, Franconia, the

remains of 800 Cave-bears were obtained. In many bone-caves are found also the bones and rude implements of *primeval man.* Of these we will speak more fully hereafter.

Fig. 874.—Skull of Ursus spelæus, × $\frac{1}{8}$.

Fig. 875.—Skull of Hyena spelæa, × $\frac{1}{4}$.

Origin of Cave Bone-Rubbish.—When it was supposed that the Drift was caused by a great wave of translation sweeping across the continent and carrying ruin in its course, the phenomena of bone-caves were supposed to give countenance to this view. Animals of all sizes and kinds were supposed to have huddled together in these caves, forgetting their mutual hostility in the sense of a common danger, and perished miserably together there.

But at present it is usually believed: 1. That these caves were the dens of the larger Carnivores, especially the Cave-bear and Cave-hyena, which dragged their prey there to devour them, and also later the abodes of men; 2. That also the floating bodies of large Herbivores, such as the Elephant, Rhinoceros, etc., were carried into them by the flooded rivers which then ran at that level; and 3. That during the Champlain epoch, when water ran through these caves in large quantities, bones and earth were drifted in from above, through fissures and subterranean

passages, and thus found their lodgment in the caves. This last was probably the principal source of the bone-rubbish in most cases.

Origin of Bone-Caverns.—In limestone regions caverns are very abundant everywhere. They do not seem to be enlarging *now;* but on the contrary to be in most cases filling up either with rubbish or with stalactitic and stalagmitic deposit. In some cases streams still run through them. It seems probable that they are mostly due to the action of subterranean waters in Champlain times. At that time full streams ran through and excavated them, partly by erosion, partly by solution. Gradually, as the Terrace elevation came on, the great streams into which these cavern tributaries ran cut down their beds to lower levels, the subterranean waters sought lower levels, and the part running through the caverns was reduced to drippings; and stalagmitic crusts covered the Champlain rubbish and preserved them. Thus, then, the date of the *caves* is Champlain; of the bone-rubbish is Champlain and early Terrace; of the stalagmitic crust is later Terrace and Recent.

2. **Beaches and Terraces.**—On these are found the remains of bodies which have floated and become stranded. The most abundant of these are remains of *Elephas primigenius* or Mammoth. It is believed that the bones of 500 individuals have been found on the coast of Norfolk and Suffolk, and over 2,000 grinders have been dredged up by the fishermen of the little village of Happesburgh (Woodward). On river-terraces associated with bones of Quaternary animals have been found also the rude implements of primeval man. We speak of these more particularly hereafter.

3. **Marshes and Bogs.**—As might have been anticipated, the remains found in these are mainly those of the *larger Herbivores*—elephants, oxen, stags, etc. It is in these that were found most of the fine skeletons of the gigantic Irish elk (*Cervus megaceros*). This magnificent elk was ten to eleven feet in height to the top of its palmate antlers, and ten to twelve feet between the antler-tips (Fig. 876).

4. **Frozen Soils and Ice Cliffs.**—As in these have been found the most perfect specimens of the Mammoth (*Elephas primigenius*), this seems to be the proper place to describe the animal.

The genus *Elephas* ranges *in time* from about the latter part of the Miocene to the present. There are about twenty fossil species known. The genus seems to have reached its maximum development in the Quaternary. During that period three species inhabited Europe, viz.: *E. antiquus*, *E. meridionalis*, *E. primigenius* (Lyell), besides two dwarf species, *E. Melitensis*, four and a half feet high, and *E. Falconeri*, three feet high, found in the Quaternary of Malta. Of these, the largest, the most numerous, and the latest, was the *primigenius* or Mammoth. This species roamed in immense herds all over Europe,

from the shores of the Mediterranean to Siberia, and extended also over the northern portions of North America. In Siberia the tusks are so abundant and so well preserved that much of the ivory of commerce is gotten from this source.

The Mammoth (Fig. 877) was over twice the bulk and weight of the largest modern species, and nearly one-third taller. It was thickly cov-

FIG. 876.—Skeleton of the Irish Elk (Cervus megaceros), Post-Pliocene, Britain.

ered with a brownish *wool*, and in parts with long hair; and was therefore well adapted to endure cold. It may seem strange that we should speak of the hair and wool and the color of an extinct animal; but perfectly-preserved specimens have been found sealed in the ice in Siberia—so perfectly preserved that, when first exposed, wolves and dogs of the present epoch fed on the flesh of this animal belonging to an extinct fauna. The whole skeleton, with portions of the skin, hair, wool, hoofs, and eyes of this animal, is now to be found in the museum at St. Petersburg. The existence of elephants so far north does not indicate a warm climate, although the Champlain epoch was doubtless

far less rigorous than the Glacial. These elephants were covered with thick wool, as was also the rhinoceros of Europe.

Quaternary Mammalian Fauna of England.—In England alone there were, in Quaternary times, of *Carnivora*, the great Cave-bear, the Cave-hyena, a tiger larger than the Bengal, the Sabre-toothed tiger, as large,

Fig. 877.—Skeleton of the Mammoth (Elephas primigenius). Portions of the integument still adhere to the head, and the thick skin of the soles is still attached to the feet.

with its flat, curved tusks, eight inches beyond the gums, besides wolves and lesser Carnivores. Of *Herbivores*, there were the Mammoth in herds, two species of rhinoceros, one hippopotamus, the great Irish elk, three species of oxen, two of them of gigantic size, besides horses, deer, and other smaller species. Surely this was the culmination of the Mammalian age in England.

Mammalian Fauna in North America.

The animals of North America, in Quaternary times, were equally abundant; but the country has been less perfectly explored, and the collections, therefore, less complete. Bone-caverns, the richest sources of European collections, are also far more rare.

Among *Herbivores*, the most remarkable were the great Mastodon (*M. Americanus*); two species of elephants, the *E. Americanus* and the *E. primigenius;* at least two gigantic bisons, one of which was probably ten feet between the horn-tips;[1] gigantic horses; gigantic beavers, one five feet long; a gigantic stag (*Cervus Americanus*), fully as large as the Irish elk; tapirs, peccaries, and a large number of *Edentates*, an order now mostly confined to South America, to which belong the sloths and armadillos. Many of these were also of gigantic size. *Carnivores* were not so abundant as in Europe. The most remarkable were a lion (*Felis atrox*), as large as the European, and two species of bear (*Ursus pristinus* and *amplidens*).

Bone-Caves.—Caves are found in limestone regions in America as elsewhere, but they do not seem to have been to the same extent the dens of Carnivores. In a vertical opening in limestone strata in Pennsylvania, a kind of cave, mammalian remains have been found belonging to thirty-four species, among which were six Edentates, eight Ungulates, and twelve Rodents. A number have also been found in the caves of Virginia, and a few in those of Illinois (Cope).

Marshes and Bogs.—Most of the remains of large Herbivores have been found in marshes and bogs. In the *Big Bone Lick*, Kentucky, the remains of one hundred mastodons and twenty elephants are said to have been dug up. Many very perfect skeletons of the great mastodon have been obtained from marshes in New York, New Jersey, Indiana, and Missouri. One magnificent specimen was found in a marsh near Newburg, New York, with its legs bent under the body and the head thrown up, evidently in the very position in which it mired. The teeth were still filled with the half-chewed remnants of its food, which consisted of twigs of spruce, fir, and other trees; and within the ribs, in the place where the stomach had been, a large quantity of similar material was found. In 1866 a very perfect skeleton was found in a bog at Cohoes, New York.

The *Mastodon Americanus* (Fig. 878) is probably the largest land-mammal known. It was twelve to thirteen feet high, and, including the tusks, twenty-four to twenty-five feet long. It differed from the

[1] A specimen of *Bos latifrons* has recently been found in Ohio, the *horn-cores* of which were twenty inches around the base, and more than seven feet between the points. Between the horn-tips must have been at least ten feet.

elephant chiefly in the character of its teeth. The difference is seen in Figs. 879, 880, 881. The elephant's tooth, given below (Fig. 880), is sixteen inches long, and the grinding surface eight inches by four inches.

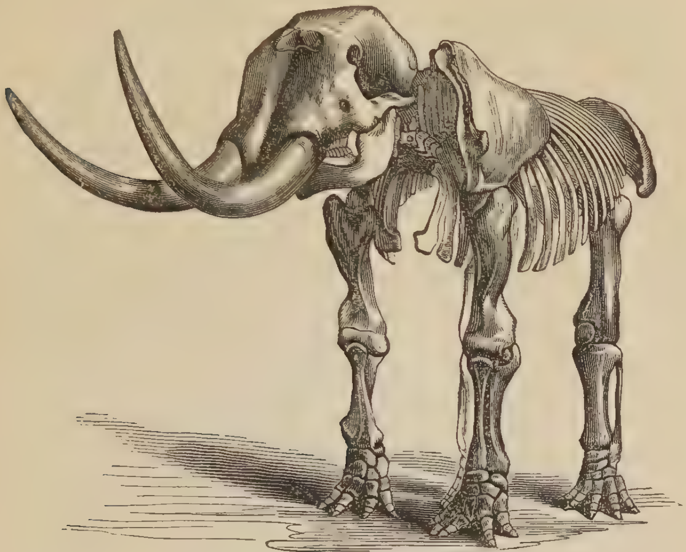


FIG. 878.—Mastodon Americanus (after Owen).

The two genera of Proboscidians, *Elephas* and *Mastodon*, appeared together, or, more probably, the mastodon a little the earlier, in the

FIG. 879.—Tooth of Mastodon Americanus.

FIG. 880.—Perfect Tooth of an Elephas, found in Stanislaus County, California, $\frac{1}{8}$ natural size.

Miocene epoch; they ranged together through the rest of the Tertiary, the species, of course, changing several times. At the end of the Tertiary, the mastodon became extinct on the Eastern Continent, but con-

tinued through the Quaternary, with its companion, the elephant, in America. At the end of the Quaternary, the mastodon became extinct wholly, and the elephant in America and Europe, though it still continues in Asia and Africa. During the Quaternary, therefore, one species of mastodon and two species of elephant roamed in herds over North America from the Gulf to arctic regions. Of the two species of

Fig. 881.—Molar Tooth of Mammoth (Elephas primigenius): *a*, grinding surface; *b*, side-view.

elephant, however, the *primigenius* was mostly confined to the higher latitudes, and the *Americanus* to the southern portions. The latter is distinguished from the former by less crowded enamel plates in the grinders and less curved tusks. Of the three genera of *Proboscidians* known, the Dinotherium appeared first, then the Mastodon, and last the Elephant. This is also the order of specialization of teeth-structure.

Among *Edentates*, a Megatherium, a Megalonyx, and several Mylodons, have been found in North America; but as their principal home was in South America, we will describe them under that head.

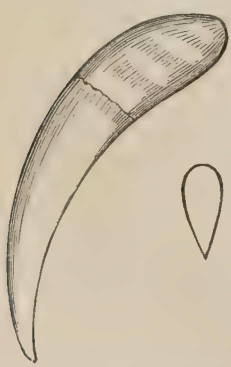


Fig. 882.—Tooth of Machairodus (smilodon) neogæus, × ½ (drawn from a cast).

River-Gravels.—In many portions of the United States, but especially in California, remains of mastodon and elephant, and bison, etc., are found in great numbers in river-gravels. The river-gravels of California are spoken of again further on.

Quaternary in South America.—A large number (more than 100) of species of mammals have been found in the soil of the pampas and in the caves of Brazil. They are mastodons (different species from the North American), llamas, horses, tapirs, rodents, many species of panther-like carnivores, large sabre-toothed tigers (*Ma-*

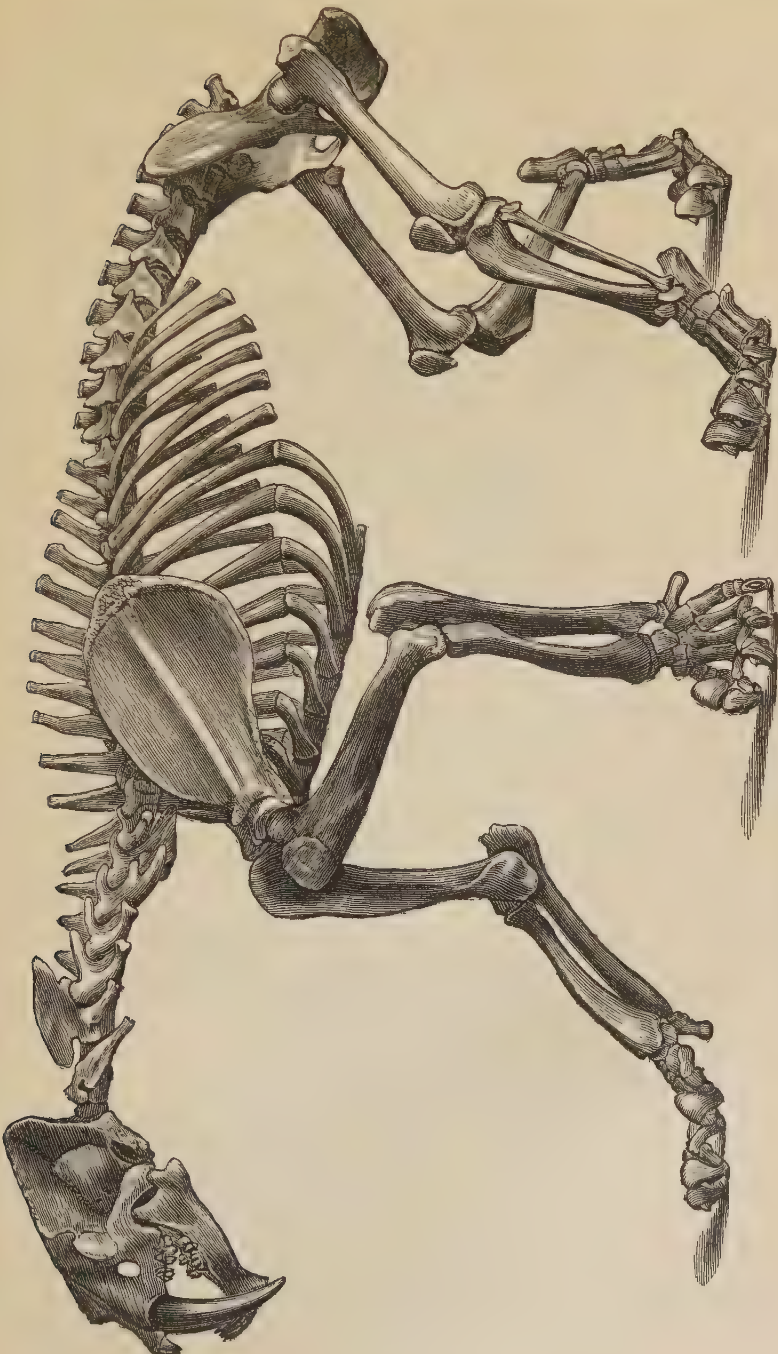


FIG. 882a.—Machærodus (Smilodon) necator, complete skeleton, × $\frac{1}{10}$ (after Burmeister).

chairodus neogœus and *necator*), with curved, sabre-like tusks twelve inches long and eight inches beyond the gums (Fig. 882), and especially a large number of Edentates allied to the sloths and armadillos, but of gigantic size.

Of the Edentates, the most remarkable, in fact, one of the most remarkable animals which have ever existed, is the *Megatherium* (great beast) *Cuvieri*. The genus Megatherium ranged in Quaternary times through South America, and into North America as far as the shores

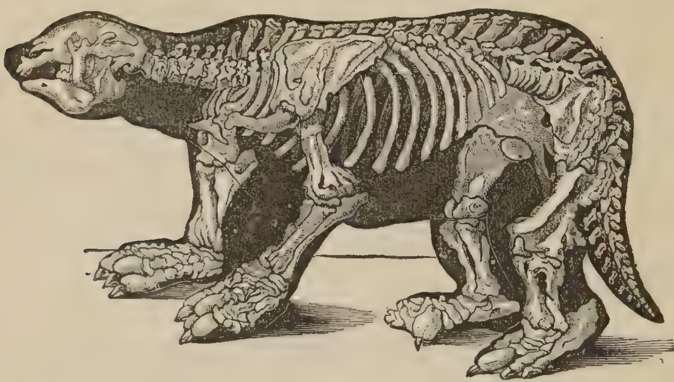


Fig. 883.—Megatherium Cuvieri.

of Georgia and South Carolina. At the mouth of the Savannah River the remains of several individuals of a species of this genus (*M. mirabilis*) have been found. But the largest species and the most perfect specimens have been found in South America.

The *Magatherium Cuvieri*, of which we give a figure above, was larger than a rhinoceros, but was still more remarkable for the clumsy

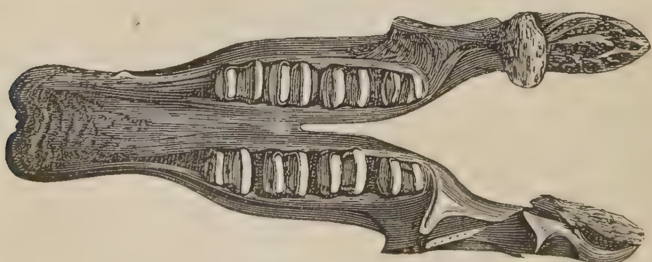


Fig. 884.—Lower Jaw of a Megatherium, showing the Gradual Surface of the Teeth (after Owen).

massiveness of its skeleton than for its size. This is especially true of its hind-legs, hip-bones, and tail. For this reason, it is supposed to have been able to stand on its hind-legs and tail, while it used its long

free-moving arms, terminated with hands a yard long, to tear down branches on which it fed. The great skeleton represented above is eighteen feet long, and its thigh-bones are three times as thick as those of an elephant. The grinding surface of its molar teeth (it had no

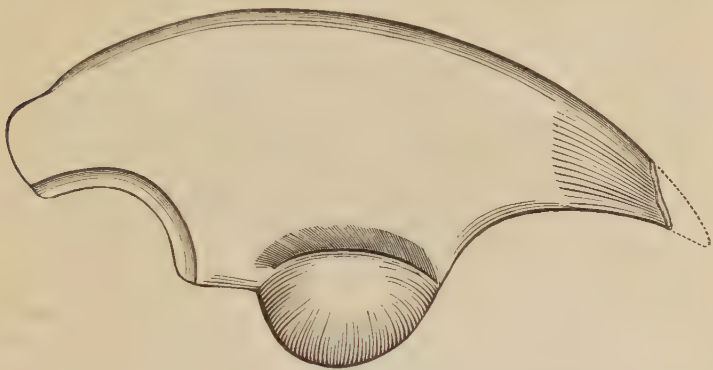


FIG. 885.—Claw-Core of a Megalonyx, × ½ (drawn from a cast of the original).

others) is traversed by triangular ridges admirably adapted to triturate its coarse food.

Megalonyx (big claw) is the name of another genus of these gigantic sloths, and *Mylodon* of a third. Both of these genera extended into North America. In fact, the Megalonyx was first discovered in Green-

FIG. 886.—Skeleton of Mylodon robustus, Quaternary, South America.

brier County, Virginia, and named Megalonyx by Thomas Jefferson. The larger species of Mylodon and Megalonyx were about the size of a buffalo, or larger.

Of the *Armadillos* or *mailed Edentates*, there were several of gigantic size belonging to the genera *Glyptodon*, *Chlamydotherium*, and *Pachytherium*. The accompanying cut represents one of these eight feet

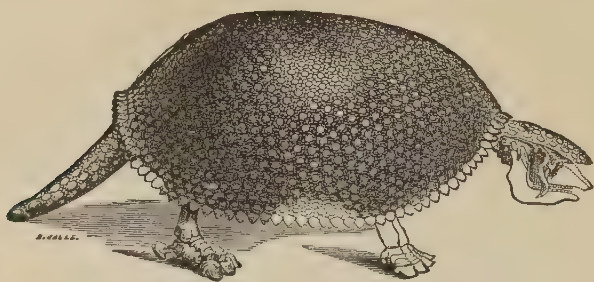


FIG. 887.—Skeleton of Glyptodon clavipes, × $\frac{1}{30}$, Quaternary, South America.

long, with an invulnerable coat-of-mail. Some species of the genus *Chlamydotherium* were much larger—one as big as a rhinoceros, and of *Pachytherium* as big as an ox (Dana).

Australia.—In Australian caves, also, great abundance of remains has been found, and they show the same prevalence of gigantic species. As *now*, so *then*, the mammals of Australia were almost all *Marsupials*, but the present species are dwarfs in comparison. The largest of these was the *Diprotodon* (two front teeth), a pachydermoid kangaroo as big as a rhinoceros. A reduced figure of the skull, which was three feet long, is given below.

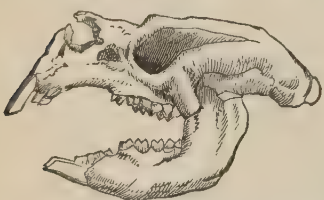


FIG. 888.—Skull of Diprotodon Australis, × $\frac{1}{30}$, Post-Pliocene, Australia.

Among other remarkable species of marsupials were *Macropus* (kangaroo) *Titan* and *M. Atlas*, of great size ; *Nototherium Mitchelli*, as large as a bullock, and a very remarkable species, supposed by Owen to have been carnivorous, and therefore called *Thylacoleo* (pouched lion) *carnifex*, as large as a lion. The striking peculiarity of this animal was the existence of a broad trenchant premolar, as shown in Fig. 889.

Geographical Fauna of Quaternary Times.—We observe, then, that already the geographical distribution of families was similar to that which we find at present. Then, as now, Herbivores greatly predominated in America, while Carnivores were very abundant, and of great size, in the Eastern Continent. Then, as now, sloths and armadillos and llamas characterized the fauna of South America, while Marsupials

characterized that of Australia. But in each locality the animal life seems to have been then more abundant, and the species gigantic.

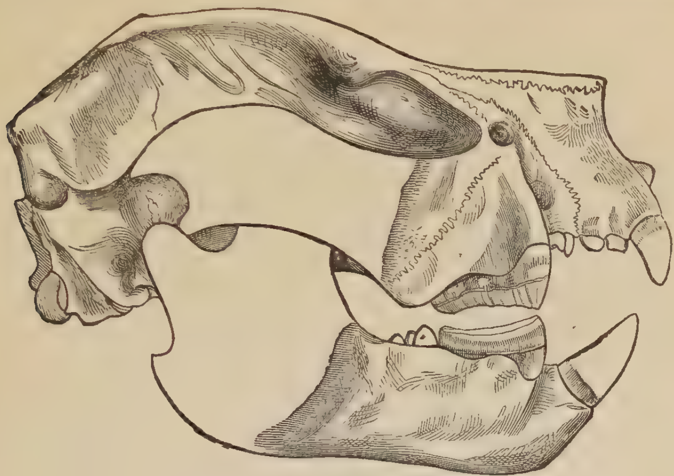


FIG. 889.—Thylacoleo, skull reduced (after Flower).

Some General Observations on the Whole Quaternary.

1. Cause of the Climate.—This is confessedly one of the most difficult questions in geology. There seems to be no doubt that, coincident with the great changes of climate, there were also great oscillations of the earth's crust in polar regions; furthermore, it seems certain that the intense cold was attended with elevation, and the subsequent moderation of climate with subsidence. This coincidence is itself strong evidence of a relation of cause and effect. It is generally admitted that increase in the *area* and height of polar lands would increase the rigor of the climate, and decrease of area and height of polar lands would moderate the climate of northern regions. The *amount* of this effect it is impossible to estimate; but the *effect* was so enormous and so wide-spread that the *cause*, even when supplemented, as it has been, by changes in the course of oceanic currents such as the Gulf Stream, has seemed to most physicists and geologists to be *insufficient*. They have cast about, therefore, for some other possible cause, external to the earth itself—i. e., cosmical cause—to explain it.

Croll's Theory.—The only theory of this kind which seems at present entitled to serious attention [1] is that of Mr. Croll (embraced also

[1] Among other cosmical causes which have been suggested ought to be mentioned secular variation in the amount of heat *emitted* by the sun. Langley (*American Journal of Science and Arts*, December, 1875) has modified this view slightly by attributing the changes of climate to variation in the amount of heat *received* from the sun; the variation being due to change in the absorptive power of the solar atmosphere.

by Geikie and many other English géologists), which attributes it to the *combined influence of precession of the equinoxes and secular changes in the eccentricity of the earth's orbit.* By the former—viz., *precession*—winter, which in the northern hemisphere occurs now when the earth is nearest the sun (perihelion), is gradually in 10,500 years brought round so as to occur when the earth is farthest off from the sun (aphelion). The effect of this, it is claimed, would be to make longer and colder winters, and shorter but hotter summers in the northern hemispheres, such as occur now in Antarctic regions. By the latter—viz., *increasing eccentricity*—these effects, which are now small on account of the nearly circular form of the earth's orbit, would become very great. At the time of greatest eccentricity, the earth would be 14,000,000 miles farther off from the sun in winter than in summer, the winters would be twenty-two days longer and 20° colder, and the summers twenty-two days shorter, but much hotter than now.

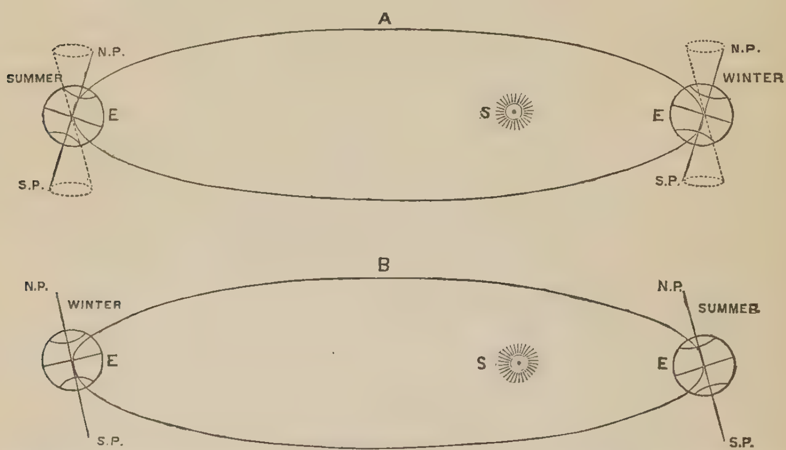


FIG. 889a.—Diagram showing effect of Precession. *A*, condition of things now; *B*, as it will be 10,500 years hence.

Fig. 889a is a diagram representing the effect of precession. In *A* we have the condition as it now exists, i. e., the north pole, N P, is turned away from the sun, S (winter), at perihelion, and toward the sun (summer) at aphelion. But the earth, rotating on its axis like a spinning-top, does not maintain the same position of its axis—does not sleep in its spinning—but wabbles on its center, the ends of the axis describing a small circle (as shown by the dotted line) in 21,000 years.[1] In 10,500 years, therefore, the axis will be tilted the other way, so that *B* represents the condition of things at that time. It is

[1] The cycle of precession is 26,000 years, but the advance-movement of the major axis of the orbit makes the cycle of aphelion winter 21,000 years.

seen that winter (north pole turned away from the sun) will be in aphelion, and summer (north pole turned toward the sun) in perihelion. Now, according to Croll, the coincidence of aphelion winter with a period of greatest eccentricity produces a glacial climate. The cycle of aphelion winter, as already said, is 21,000 years, that of greatest eccentricity is much longer and far less regular.

Again, these effects, Croll thinks, would be still further increased by changes in the direction of oceanic currents. During aphelion winter in northern hemisphere the *equator of heat* would be *south* of the geographical equator instead of north of it, as at present. The equatorial current of the Atlantic (p. 39), instead of turning northward to form the Gulf Stream, would be turned southward by the wedge-shaped eastern point of South America, and the northern hemisphere would be still further chilled by the withdrawal of this great moderator of northern climates. Finally, to all these effects must now be added the important effect of the *extreme range of temperature* during an aphelion-winter period, especially at a time of maximum eccentricity. McGee[1] has shown that the effect of *increased range* is to diminish the mean temperature, while Hill[2] has shown that it increases the *mean evaporation*, and therefore the mean precipitation, as snow.

If this theory be true, one corollary is the recurrence of Glacial epochs many times in the history of the earth. Another, according to Croll, is the alternation of colder and warmer periods many times during every period of greatest eccentricity, and a similar alternation of each between the two poles, so that the cold period at one pole corresponds with the warm period at the other. Of the alternation of colder and warmer periods during the Glacial epoch there are many evidences both in Europe and America, but it is more than doubtful if these were so numerous (seven or eight) as the theory requires. Of the recurrence of many Glacial epochs in the history of the earth there is as yet no reliable evidence, but much evidence to the contrary. It is true that what seem to be Glacial drifts, with scored bowlders, etc., have been found on several geological horizons, but these are usually in the vicinity of lofty mountains, and are probably, therefore, evidences of *local* glaciation, not of a *Glacial epoch.* On the other hand, all the evidence derived from fossils plainly indicates warm climates even in polar regions during all geological periods until the Quaternary. The evidence at present, therefore, is overwhelmingly in favor of the *uniqueness* of the glacial epoch. This fact is the great objection to Croll's theory.

Mr. Wallace has recently attempted to remove this objection by

[1] *American Journal*, vol. xxii., p. 437, 1881.
[2] *Geological Magazine*, vol. 8, p. 481, 1881.

modifying Croll's theory. He substantially accepts Croll's view, but thinks that astronomical changes alone will not produce a glacial epoch, but must be coincident with geographical changes favoring the same result. He maintains that, until the Quaternary, geographical conditions favored warm, uniform climates, especially by several open current-ways from tropical to polar seas, notably one from the Indian Ocean through Western Asia; and that at the beginning of the Quaternary these warm currents were cut off by northern elevation, which we know occurred at this time, while the elevation itself would tend still further to increase the cold. The Glacial epoch was therefore the result of several causes, astronomical and geographical, viz.: aphelion winter, maximum eccentricity, and northern elevation. On this view it is easy to see why there should have been but one Glacial epoch. This seems to be by far the most probable view yet presented.

Furthermore, Mr. Wallace thinks that, during a period of maximum eccentricity, the great accumulation of ice, once effected, would conserve the cold and tide over the shorter precessional cycles, so that these would have but little effect, and hence there would not be, and in fact were not, seven or eight alternations of cold and hot periods during the Glacial epoch, as Croll thinks. There was but one interglacial period, and this was determined by changes in eccentricity, as seen in Fig. 890.

2. **Time involved in the Quaternary Period.**—If we accept Croll's and Wallace's view, then it is possible to estimate with accuracy the length of the Glacial epoch and the time elapsed since its close, for it is needless to say that astronomical cycles are calculable with great certainty. The following diagram taken from Mr. Wallace shows the

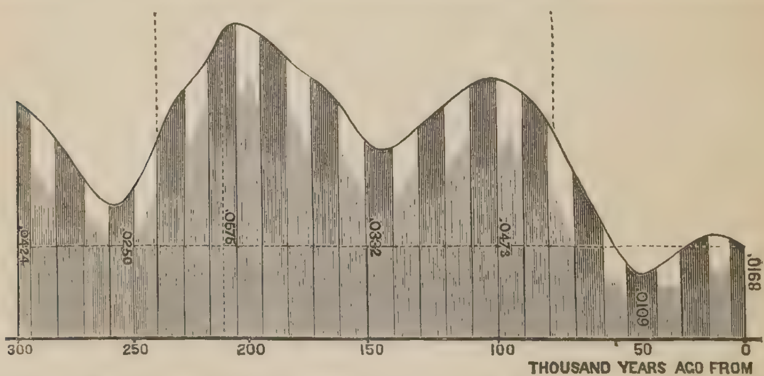


FIG. 890.—Diagram of eccentricity and precession. The dark and light shades show the warmer and colder winters, and therefore indicate each 10,500 years, the whole representing a period of 300,000 years.

degrees of eccentricity during the last 300,000 years, and the recurring cycles of precession during that period. If, as he thinks, the cold was

mainly due to eccentricity and geographical changes, the precessional changes having little effect, then this figure will also represent the degrees of cold. It is seen that, according to Croll and Wallace, the glacial period commenced 240,000 years ago, lasted 160,000 years, and 80,000 years have elapsed since its close. It is seen also that Mr. Wallace makes but one interglacial period instead of eight, the effect of the shorter precessional cycles being tided over by the effect of the accumulated ice.

On any view as to the cause of the glacial climate, there can be no doubt that the changes which produced it were effected very slowly, and therefore involved long periods of time, so slowly that they would probably be unobserved by contemporaneous man, if such existed. There are changes by elevation and depression now going on in various parts of the earth which are probably as rapid as those of the Glacial and Champlain epochs. The shores of the Baltic and of Norway are now rising at an average rate of two and a half feet per century. Continue this for 800 centuries, and Norway would attain an elevation as great as that of the Glacial epoch, and, if such elevation produces cold, would be again *ice-sheeted.* Depression at a similar rate for the same time would bring about a condition similar to that of the Champlain epoch. Yet these changes are unremarked, except by the eye of Science. The only difference, if any, between what is in progress now and what took place in Glacial times, is the comparative *universality* of the oscillations *then*, and especially their coincidence with certain astronomical changes, which greatly increased their effect upon climate.

3. The Quaternary a Period of Revolution—a Transition between the Cenozoic and the Modern Eras.—We have already seen (pp. 280 and 291) that between the great eras, and perhaps also at other times, there have been periods of *oscillation* of the earth's crust, and therefore of changes of *physical geography*, marked by unconformity of strata; and changes of *climate*, marked by apparently abrupt changes of species. These have been the *critical* periods of the earth's history—periods of revolution and rapid change. But for that very reason they are also periods of *lost records.* We have already spoken of the lost interval at the end of the Archæan, evidently the greatest of all; again, of a lost interval at the end of the Palæozoic, partly recovered in the Permian, evidently the next greatest; again, of a lost interval at the end of the Cretaceous, in a large measure recovered in the Rocky Mountain region. There are doubtless many others of less extent. These periods are always marked by unconformity of the strata and change in the life-system. The old geologists regarded these changes as sudden and cataclysmic. All geologists now regard the suddenness as largely apparent, and the result of *lost record.*

Now, the *Quaternary is also a critical period.* It corresponds with one of the lost intervals; only, in this case, on account of its nearness to us, the record has been recovered. By the study of this period, therefore, we may hope to solve many problems which have heretofore puzzled us. Here, for example, we have oscillations of the crust on a grand scale, producing great changes of physical geography and climate, and therefore of fauna and flora. Here we have unconformity, now being produced by sedimentation on old eroded land-surfaces in all the region affected by the oscillations—marine sediments in fiords and river sediments in old river-channels. But we observe that in this case these effects have been produced slowly, and that the fauna and flora have *not* been suddenly destroyed and suddenly recreated, but have continued to live throughout, the species gradually changing. But, what is still more interesting, much light is thrown also on the hitherto insoluble problem of the mode and the cause of the comparatively rapid change of species in these critical periods. The attentive study of the Quaternary shows that, in addition to the direct effect of change of climate, one great cause of change of species has been *migration:* migration north and south, *enforced* by change of temperature; migration in any direction, *permitted* by change of physical geography. This point is so important, that we must explain it somewhat fully.

It will be remembered (p. 503) that in Miocene times Greenland, Iceland, and Spitzbergen, were covered with a luxuriant temperate vegetation. The congeners of their vegetation at that time are found now in California, along the shores of the Southern Atlantic States, and in Southern Europe. Evidently at that time there was *no polar ice-cap*, and therefore *no arctic plants.* At the end of the Pliocene, the vegetation shows a climate not greatly differing from the present. It is probable, therefore, that the cold had increased until an ice-cap had formed, such as now exists in polar regions, with its accompaniment of arctic species. As the Glacial epoch came on and culminated, the polar ice-cap slowly extended—its margin crept slowly southward, until it reached 40° in America and 50° in Europe and Asia, with local extensions stretching still farther southward, in the form of separated glaciers. The southern polar regions were probably similarly affected, either simultaneously or alternately.

We must not confound this movement southward of the southern limit of the ice with the *current motion* of the ice-sheet itself. The limit of the ice-cap is like the lower limit of a glacier (p. 44). It may be stationary, or advancing or retreating, but the glacial stream flows ever onward. Again, the motion of a glacial current is slow—perhaps one to three feet *per day*—but the extension or recession of the glacial limit is far slower, perhaps a few feet *per annum.* We may thus easily appreciate the immense time necessary to advance this limit of the ice-cap to 40° latitude.

At the end of the Glacial and the commencement of the Champlain epoch a movement of the ice-limit in a contrary direction—a retreat northward—commenced and continued, with perhaps some alternate progressions and regressions, to its present position.

Now, the effect of this advance and retreat of polar ice upon plants and animals must have been very marked. Temperate plants, inhabiting Greenland in the Miocene, were pushed to the shores of the Gulf. Arctic plants—i. e., those which haunt the margin of perpetual ice—were pushed to Middle United States and to Middle Europe ; and arctic shells were similarly driven southward, *slowly*, generation after generation. We say *slowly*, for otherwise they must have been destroyed. With the return of temperate conditions, and the retreat of the ice-cap, these species, both shells and plants, again went northward to their appropriate place. But the plant species, and some land invertebrate species, such as insects, had an alternative which the shells had not, viz., to seek arctic conditions also *upward* on mountains. Many did so and were left stranded there. Thus is explained the remarkable fact that *Alpine* plant-species in Europe are similar to and largely identical with those in America ; and both with the present *arctic* species. This indicates a former wide distribution of identical arctic species all over Europe and America, and their subsequent retreat *northward* into polar regions, and *upward* into Alpine isolation. Recently Grote has observed a similar isolation of Labrador insect-species on Mount Washington and on the Colorado mountains.[1]

There was probably a similar movement, to a less extent, of temperate species. In the Taxodium of the Southern Atlantic and Gulf swamps, and the Sequoias of California, we doubtless have examples of species wide-spread in Miocene times, which have been destroyed by these climatic changes, except in certain limited areas.

But plants and lower species of animals are far less affected by changes in physical conditions than are the higher species of animals. This is shown by the wide range both in space and time of the former as compared with the latter. Under these great changes and enforced migrations, therefore, plants and invertebrate animal species maintained their specific characters mostly unchanged, or but slightly changed. But in the case of mammals destruction or change was inevitable. Both took place—destruction of some and change of the remainder.

In America during Quaternary times there was *probably* a broad land-connection of North America with South America by the Caribbean Sea region ; and certainly, as shown by the similarity of plants, with Northern Asia, by the region between the Aleutian Isles and Behring Straits. Thus migrations were not only enforced by climatic changes, but permitted by geographical connections with adjacent con-

[1] *American Journal of Science*, 1875, vol. x., p. 335.

tinents. Also the great Pliocene lake (p. 500) which separated Western from Eastern North America was abolished, and migrations established between the East and West. It is evident that from all these causes mammalian faunæ from widely-different regions were precipitated upon each other, and struggled together for mastery. Large numbers of species were destroyed, and the fittest only survived, and these only under changed forms. It is quite possible that man came to America with the Asiatic mammalian invasion. If so, his earliest remains in America may be looked for on the Pacific coast.

Of course, we use the word *migrations* in its widest sense, as change of habitat of species as well as of individuals. In the case of plants and many lower animals, the place of species only moved slowly, from generation to generation. In the case of mammals there was more decided movement of individuals.

This very important subject has been more closely studied in Europe than here, although we believe that America is the simplest and best field for its elucidation. During the Quaternary probably at least four distinct mammalian faunæ struggled together for mastery on European soil: 1. The Pliocene autochthones. 2. Invasions from Africa, permitted by geographical connection opening a gateway through the Mediterranean, since closed. 3. Invasions from Asia, by opening of a gateway which has remained open ever since; with this invasion probably came man. 4. Invasions from arctic regions. Probably more than one such invasion took place; certainly one occurred during the second Glacial epoch, called on that account the Reindeer period.

The final result of all this struggle was, that the Pliocene autochthones were destroyed or driven southward in Africa; the southern species were mostly destroyed or driven back, with changed forms and diminished size; the northern species, reindeer, glutton, etc., retreated again northward, and the Asiatics remained in possession of the field, but greatly changed by the struggle. Man was among these, and certainly one of the principal agents in the change. Speaking more accurately, the present fauna of Europe may be said to be a product of all these factors; but the Asiatic invasion seems to be the largest factor.

Thus, then, the gradual progress of evolution, and the causes of the phenomenon of rapid change of species at critical periods of the earth's history, may be briefly summarized as follows:

1. A gradual, *extremely slow* evolution of organic forms under the operation of all the forces and factors of evolution known and unknown, whatever we may conceive these to be. This cause acting alone would produce gradual changes in time (geological fauna), but without geographical diversity.

2. This slow evolution takes different directions in different places and under different physical conditions, and thus gives rise to *geo-*

graphical faunas and floras. Such geographical faunas and floras, if isolated by physical barriers, become more and more diverse so long as the barriers are maintained. This cause acting alone would produce extreme geographical diversity, and render determination of synchronism impossible.

3. During *critical periods physical changes* and consequent *migrations*, partly enforced by changes of climate, partly permitted by removal of barriers, and the precipitation of adjacent faunas and floras upon each other, and the consequent severe struggle for life, give rise to *far more rapid changes of species*, but at the same time to greater geographical uniformity. This more rapid change of organic forms is produced partly by *severer pressure of external conditions*, certainly one factor of change; partly by *severer struggle for life*, certainly another factor of change; and doubtless partly also by the more active operation of *other factors of change*, which we do not yet understand. This last cause tends to produce not only more rapid general evolution, but also to destroy extreme geographical diversity; and since it operates on animals rather more than plants, plant species are more apt to be local, and are less certainly carried along with the stream of general evolution, and are, therefore, less reliable in determining geological age than animals.

The last of these critical periods was the Quaternary. Therefore in the changes of physical geography and climate of this period we find the *main cause of the present distribution of species;* and, conversely, this distribution furnishes the key to the geographical changes and the direction of migrations during the Quaternary.

Thus, then, regarding the *Cenozoic* and the *Modern* as consecutive eras, and the Quaternary as the transitional, revolutionary, or critical period between, we see a *great*, and, if we had lost the Quaternary, an apparently *sudden*, change of species. Yet this change, as great as it is, is not to be compared in magnitude with that which separates the great eras or even ages from each other. Evidently, therefore, we must regard the lost interval between the Archæan and Palæozoic, and that between the Palæozoic and Mesozoic, yes, even that between the Mesozoic and Cenozoic (as small as this latter is in comparison with the others), as all of them far greater than the whole Quaternary period; or else the forces of evolution must have been far more active in those earlier times than more recently.

4. **Drift in Relation to Gold.**—We have already stated (p. 240) that gold occurs in two positions, either in quartz-veins intersecting metamorphic slates (quartz-mines) or in drift-gravels (placer-mines). The auriferous slates may be of various ages. In the Appalachian chain, and in the Ural Mountains, and in Australia, the slate or schist is metamorphic *Silurian.* In California it is *Jura-Trias.* The placer gold deposits are everywhere *Quaternary drift-gravels.*

There has been throughout all geological time a progressive concentration of gold, as well as many other metals, in a more and more available form: 1. It was first *disseminated* in excessively small quantities, too small to be detected, *through the slates*, derived doubtless from the sea, in the waters of which it is detectable in very small quantities. 2. After the upheaval, crumpling, metamorphism, and fissuring of these slates, the gold was dissolved, and accumulated, along with silica and metallic sulphides, in these fissures, as auriferous veins. 3. Atmospheric agencies acting on these outcropping veins dissolved away the sulphides, and left the gold in a still more available form along the backs of the veins. 4. Then came the ice-sheet and the glaciers of the Quaternary, like a plough, cutting away the backs of the quartz-veins, together with the containing slates, and, like a mill, grinding all to gravel, and heaping it away in moraines. Some of the placer-mines are in these moraines, but most of the gold has been subjected to still another process 5. Lastly, in the Champlain epoch, the river-floods washed these moraine-heaps down the rivers, sorting them and depositing where the velocity of the current diminished. These river-gravels, thus sorted, cradled, *panned* by the action of currents, and therefore with the coarse gold near the bottom and high up the gulches, constitute the richest placer-mines.

The placers of California, however, are of two kinds, viz., the ordinary or superficial placers, and the *deep placers.* The superficial placers are gravel-drifts in the present river-beds. The deep placers are gravel-drifts in *old river-beds.* These old river-beds, as already stated (pp. 248, 555), are in many cases covered up with lava. Usually the general direction of the old bed coincides with that of the present river-system, but sometimes the present river-system cuts across the old river-system. In all cases, however, it is evident that the old river-gravels were formed before the lava-flow, and the newer gravels after the lava-flow. In all cases also the present river-system has cut down *far below the old beds*, in this respect entirely different from the old river-beds of the eastern portion of the continent.

The following figures are ideal sections altered a little from Whitney's: Fig. 891, of a case in which the old and the present river-beds are parallel to each other; Fig. 892, where the latter cut through the former. In the former case the section is across the lava-flow, as well as across the river-beds; in the latter case it is in the direction of the lava-flow, and therefore of the old river-bed, but across the present river-bed.

In Fig. 891, which is a section across Table Mountain, in Tuolumne County, California, L is the lava-cap, 140 feet thick, beneath which is the old river-bed, R, with its gravel, G, now worked by a tunnel, driven through the *rim-slate* S. More recent gravels, G', are seen in the pres-

ent river-beds, R'. In this locality G represents the deep placers, and G' the superficial placers.

The history of changes shown in these sections is sufficiently obvious. In the time of the old river-system, R was a river-bed, doubt-

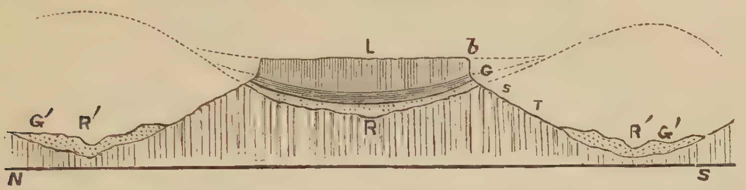


FIG. 891.—Section across Table Mountain, Tuolumne County, California: *L*, lava; *G*, gravel; *S*, slate; *R*, old river-bed; *R′*, present river-bed.

less with a ridge on either side represented by the dotted lines. In this bed accumulated gravel, containing gold. Then came the lava-flow, which of course ran down the valley, displacing the river and

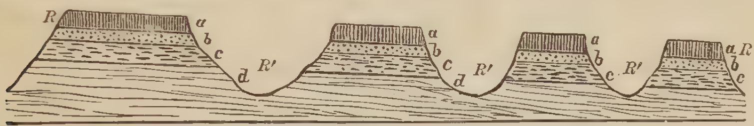


FIG. 892.—Lava-Stream cut through by Rivers: *a*. *a*, basalt; *b*, *b*. volcanic ashes; *c*, *c*, Tertiary; *d*, *d*, Cretaceous rocks; *R* *R*, direction of the old river-bed; *R* , *R* , sections of the present river-beds (from Whitney).

covering up the gravels. The displaced rivers now ran on either side of the *resistant* lava, and cut out new valleys, 2,000 feet deep, in the solid slate, leaving the old lava-covered river-beds and their auriferous gravels high up on a ridge. In other cases the convulsion which ejected the lava also changed greatly the general slope of the country, and therefore the direction of the streams. In such cases of course the present river-system cuts across the old river-beds and gravels, and their covering lavas, as shown in Fig. 892.

Age of the River-Gravels.—The age of the old river-gravels is still doubtful; that of the newer river-gravels is undoubtedly Champlain or early Terrace. Below we give a list, taken from Whitney, of the remains found in these gravels:

Newer placers.	Great mastodon. Mammoth. Bison. Tapir, modern. Horse, modern. Man's works.
Deep placers.	Great mastodon.[1] Mammoth. Tapir, modern. Rhinoceros (ally). Hippopotamus (ally). Camel (ally). Horse, extinct species.

[1] Whitney states that the mastodon is not found here, but it has been since found.

It will be seen that the fauna of the deep placers unite Pliocene and Quaternary characters. The great mastodon, the mammoth, and the tapir, are distinctively Quaternary, while the others are Pliocene. The plants, according to Lesquereux, are decidedly Pliocene. Therefore Whitney has not only placed the deep placers in the Pliocene, but made them the representative of the whole Pliocene, and probably Miocene, and the lava-flow as the dividing-line between the Tertiary and Quaternary. But, all the facts considered, it seems most probable that both the filling of the old river-beds, and their protection by lava, took place comparatively rapidly, and were together the closing scene of the Tertiary drama. The deep gravels, therefore, may be placed indifferently in the latest Pliocene or earliest Quaternary. The newer gravels are undoubtedly Quaternary and recent. Certain it is that the deep placer-gravels are similar in all respects to the Quaternary gravels all over the world, except that, by percolating alkaline waters containing silica, they have been cemented in some cases into grits and conglomerates. This is because they are covered with lava which yields both the alkali and the soluble silica, as already explained (p. 248).

In any case, we have here an admirable illustration of the immensity of geological times. The whole work of cutting the hard slate-rock 2,000 feet or more has deen done since the lava-flow, and therefore certainly since the beginning of the Quaternary.

CHAPTER VI.

PSYCHOZOIC ERA—AGE OF MAN—RECENT EPOCH.

Characteristics.—The Quaternary, and, indeed, all previous ages, were reigns of *brute force* and *animal ferocity.* A condition of things prevailed which was inconsistent with the supremacy of man. The age of man, on the contrary, is characterized by the *reign of mind.* Therefore, as was necessary, the dangerous animals decreased in size and number, and the useful animals and plants were introduced, or else preserved by man.

Distinctness of this Era.—In regard to the distinctness and importance of this era, there are two views which will probably ever divide geologists, depending on the two views regarding the relation of man to Nature. From the purely structural and animal point of view, man is very closely united with the animal kingdom. He has no department of his own, but belongs to the vertebrate department, along with quadrupeds, birds, reptiles, and fishes. He has no class of his own, but belongs to the class Mammalia, along with quadrupeds. Neither has he

an order of his own, but belongs to the order of Primates, along with monkeys, lemurs, etc. Even a family of his own, the *Hominidæ*, is grudgingly admitted by some. But from the psychical point of view it is simply impossible to overestimate the space which separates man from all lower things. Man must be set off not only against the animal kingdom, but against the whole of Nature besides, as an equivalent: Nature the *book*—the revelation—and man the *interpreter.*

So in the history of the earth: from one point of view the era of man is not equivalent to an era, nor to an age, nor to a period, nor even to an epoch. But from another point of view it is the equivalent of the whole geological history of the earth besides. For the history of the earth *finds its consummation, and its interpreter, and its significance, in man.*

The *rocks* of this epoch are the present river-deposits, lake-deposits, sea-deposits, volcanic ejections, etc., already treated of in Part I. The *fauna and flora* of this epoch are the species *still living* on the earth. These are different from those of the Tertiary, and largely from those of the Quaternary, times; but the change, as we have already shown, has been gradual, not sudden; man himself being one of the chief agents of change.

FIG. 893.—Dinornis giganteus, × $\frac{1}{38}$ (from a photograph of a skeleton in Christchurch Museum, New Zealand).

FIG. 894.—Aptornis didiformis, × $\frac{1}{10}$ (from a photograph of a skeleton in Christchurch Museum, New Zealand).

The Change still in Progress—Examples of Recently-Extinct Species. —The gradual change of fauna has been going on through many ages, and is still going on under our eyes. Many remarkable Quaternary species have lingered, and become extinct by the agency of man, even in historic times. Among the most remarkable of these are the huge wingless birds, the remains of which have been discovered in New Zealand and Madagascar, viz., the *Dinornis* (huge bird), *Æpiornis* (tall bird), *Palapteryx* (old wingless bird), the Solitaire, and the Dodo. Through the kindness of Mr. C. D. Voy, I am able to give good figures of the skeletons of several of these extraordinary extinct birds, taken from photographs (Figs. 893, 894).

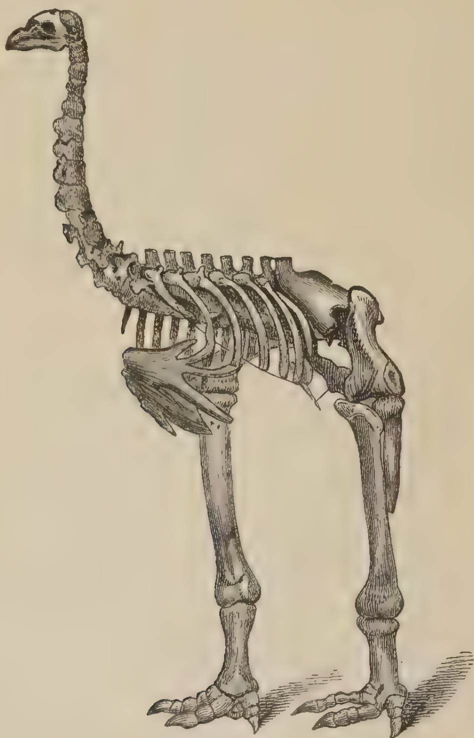


FIG. 895.—Dinornis elephantopus, $\frac{1}{18}$ (after Owen).

The *Dinornis giganteus* of New Zealand, and the *Æpiornis* of Madagascar, were probably twelve feet high. The tibia of the former has been found nearly a yard long, and as thick as the tibia of a horse, and the egg of the latter, well preserved, thirteen inches long and nine inches in diameter, with a capacity of two gallons. The toe-bones of the *D. elephantopus* (Fig. 895) rivaled in size those of an elephant (Owen).

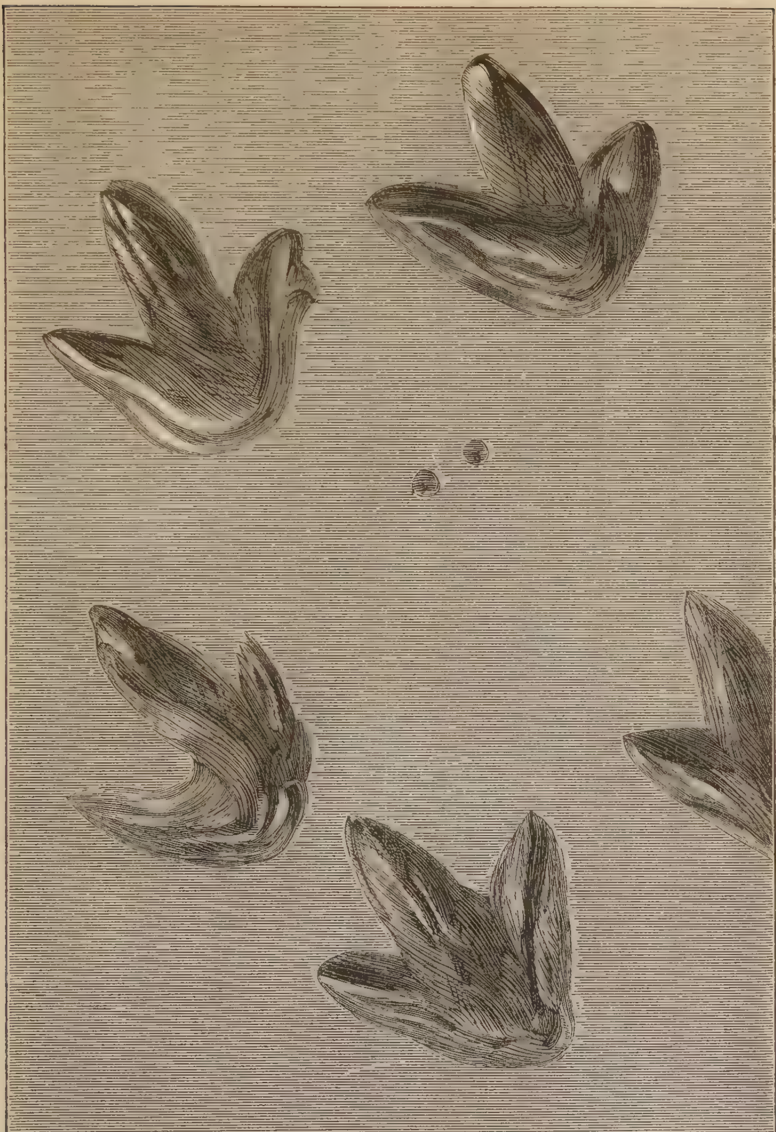


FIG. 895a.—Footprints of Dinornis (Moa), a recently extinct bird, on a slab of soft sandstone, two feet by three feet, probably of Post-drift Age. A fac-simile cast, showing the footprints in relief, which were made from the original sandstone. Length of stride, 19 inches; track from heel to toe, 8 inches; from first claw to third claw, 8¼ inches; the extreme depth of heel, about one to one and a quarter inch below the surface of the rock. Similar tracks have been found at various times in the same locality. Found October, 1875, by C. D. Voy, at Gisborne, Poverty Bay, New Zealand.

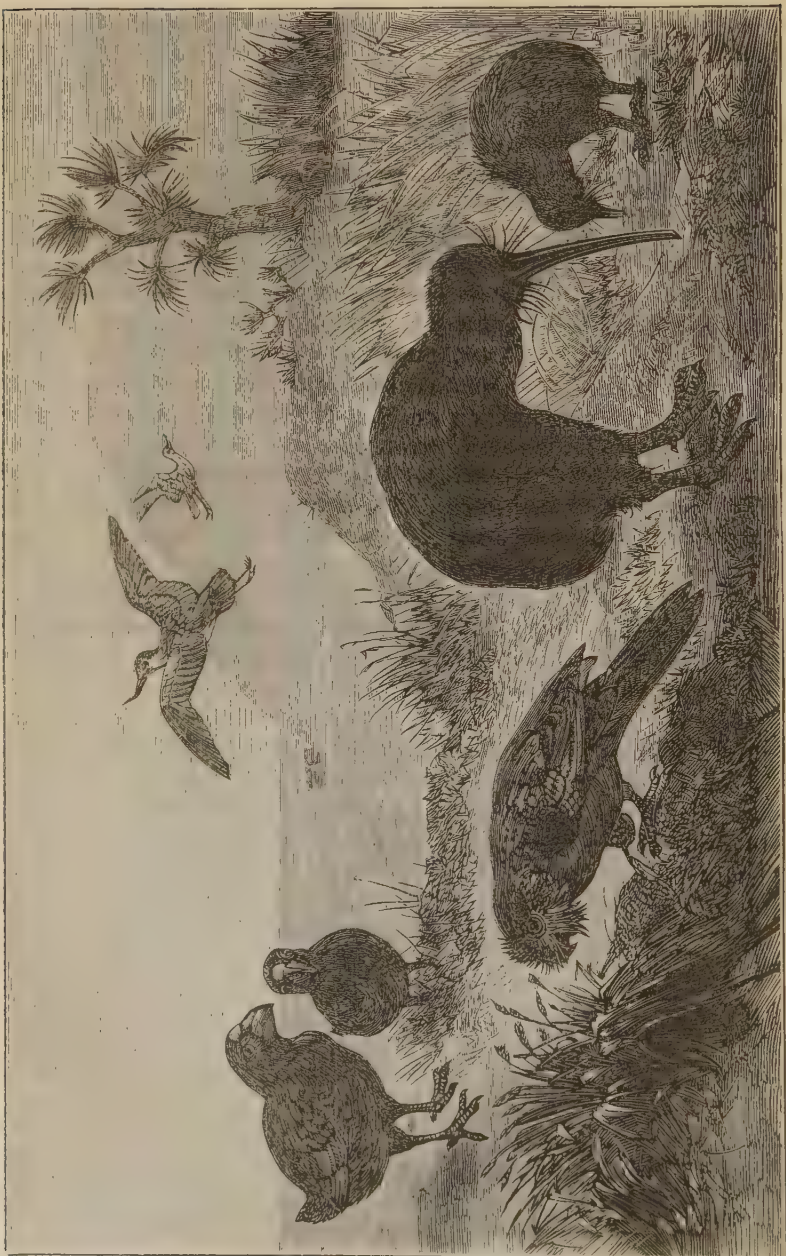


FIG. 896.—Australian Birds. Apteryx Australis in foreground, at the right.

These huge birds must have been capable of making tracks nearly as large as those of the supposed birds of the Connecticut Valley sandstone (p. 456). Such tracks have indeed been recently found in New Zealand, in a very soft sandstone. Through the kindness of Mr. Voy, I am able to give in Fig. 895a a copy of photograph of such tracks obtained by him. The dodo, a heavy, clumsy bird, of fifty pounds' weight, with loose, downy feathers, and imperfect wings, like a new-born chicken, became extinct only about 150 or 200 years ago. The *Apteryx*, to which, of all living birds, the *Dinornis*, *Aptornis*, etc., are most nearly allied, still survives, ready to disappear (Fig. 896).

The *Bos primigenius*, the gigantic ox of Quaternary times, is supposed to be the same as the *Urus* of Cæsar, and therefore became extinct since Roman times. The aurochs, another Quaternary ox, would have been now entirely extinct but for the imperial edict which preserves a few in the forests of Lithuania. The lion, the tiger, the bison, the elephant, and the rhinoceros, and, in fact, all the fiercer and larger animals, are even now disappearing before the advance of civilized man.

Thus, in passing from geological to present times, we trace rocks into sediments and soils; geological agencies into chemical and physical agencies, now in operation; extinct faunæ and floræ into the living fauna and flora; in a word, geology into chemistry and physics, and paleontology into zoölogy and botany.

Now, in this gradual change of fauna, *when* did man first appear upon the scene, and *what was the character* of primeval man? This introduces us to two very important but very difficult and obscure subjects.

I.—Antiquity of Man.

On this interesting subject the three sciences—History, Archæology, and Geology—meet and coöperate; and the recent rapid advance has been the result of this union, and especially of the application of geological methods of research.

Archæologists have long ago divided the history of human civilization into three epochs or *ages*, named, from the materials of which weapons and tools are made, respectively the *Stone age*, the *Bronze age*, and the *Iron age*. We are here concerned only with the *Stone* age; the others belong to history.

Closer study has again divided the Stone age into two, viz., the *Palæolithic* (old Stone age) and the *Neolithic* (newer Stone age). During the former, only *chipped* stone implements were used; while in the latter *polished* stone implements were *also* used. It is principally with the *Palæolithic* that we are here concerned.

Still closer study, in connection with geology, has again divided the Palæolithic into an earlier and a later. The earlier, being contempora-

neous with the mammoth, is called the *Mammoth age;* and the latter, for similar reasons, the *Reindeer age.* The mammoth, however, existed also in this latter age. The former seems to correspond with the Champlain epoch in geology, and the latter with the Terrace of America, or Second Glacial epoch of Europe. The Neolithic commences the Psychozoic era, or *reign of man*—the period when *man had established his supremacy.* The following table expresses these views:

3. Iron age			Psychozoic era.
2. Bronze age			Psychozoic era.
1. Stone age	Neolithic—Domestic animals.		Psychozoic era.
1. Stone age	Palæolithic.	Reindeer age	= Terrace or Second Glacial epoch.
1. Stone age	Palæolithic.	Mammoth age	= Champlain epoch.

These divisions and their relations to geological epochs have been established *in Europe.* They would probably apply also to some parts of Asia and Africa, for in portions of these old countries man has doubtless passed, successively and slowly, through all these stages. But all these stages are not represented in all countries, nor do they necessarily correspond to the geological epochs mentioned above. The South-Sea-Islanders, for example, are still in the Stone age. The American Indians were in the Stone age only three centuries ago.

The table given above carries man back to the Champlain epoch. There are some geologists who think they find evidence of a much earlier existence of man. We will, therefore, very rapidly review the evidences of the antiquity of man. In doing so, however, we shall accept none but thoroughly reliable evidence. There has been recently far too much eagerness to find facts which overthrow accepted beliefs, and to accept them on this account alone. We will take up European localities first, because the subject has been more carefully studied there.

Primeval Man in Europe.

Supposed Miocene Man—Evidence unreliable.—The earliest period in the strata of which any supposed evidences of the existence of man

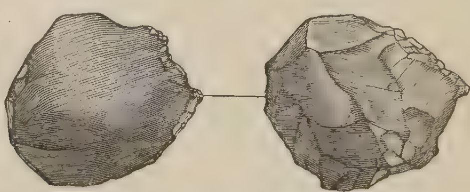


FIG. 896a.—Flint flakes[1] collected by Abbé Bourgeois from Miocene Strata at Thenay (after Gaudry). Natural size.

[1] See APPENDIX.

have been found is the *Miocene.* These evidences, however, are confessedly meagre, and by all careful investigators considered unreliable. Some flint-flakes (Fig. 896a), so rough that they may be the result of physical instead of intelligent agencies; some bones of animals, marked with parallel scratches as if *scraped*, but the scratches may have been produced by currents, or, as Lyell thinks, by the teeth of Rodents; some more positive evidences of man's agency, but in strata of more doubtful age, or else the result of accidental mixture not contemporaneous with the deposit itself—such is, in brief, the evidence. The Miocene man is not acknowledged by a single careful geologist.

Supposed Pliocene Man.—The evidence of the existence of man during the Pliocene period is, if possible, still more meagre and unreliable. M. Hamy thinks he has found undoubted evidence of human agency in flint implements in Pliocene strata at Savone; but the contemporaneousness of the flints and the deposit is regarded as doubtful. Again, Palæolithic implements have been found in Madras in strata supposed by Falconer to be Pliocene; but more recent investigations make the strata Quaternary.[1] Of the supposed Pliocene man in California we will speak further on. Suffice it to say that M. Favre, reviewing the whole subject up to 1870,[2] and, again, Evans, President of the Geological Society of London, reviewing the subject up to 1875,[3] and Dawkins in 1879, and Lubbock in 1881,[4] decide that the existence of Tertiary man is yet unproved.

Quaternary Man—Mammoth Age.—But of the existence of man in Europe and America, as early as the middle of the Quaternary period, there seems to be abundant evidence. We shall select only a few striking examples:

a. **In River-Terraces.**—In the terraces of the river Somme, near Abbeville, were found, nearly twenty years ago, by M. Boucher de Perthes, chipped flint implements, associated with bones of the mammoth, rhinoceros, hippopotamus, hyena, horse, etc. The doubts with which the

FIG. 897.—Section across Valley of the Somme: 1, peat, twenty to thirty feet thick, resting on gravel, *a*; 2, lower-level gravels, with elephant-bones and flint implements, covered with river-loam twenty to forty feet thick; 3, upper-level gravels, with similar fossils covered with loam, in all, thirty feet thick; 4, upland-loam, five to six feet thick; 5, Eocene-Tertiary.

first announcement of these facts was received have been entirely removed by careful examination of the locality by many scientists, both of France and England.

The findings were in undisturbed gravels, both lower (2) and upper

[1] *American Journal of Science*, 1875, vol. x., p. 232.

[2] "Bibliothèque Universelle," "Archives des Sciences," vol. xxxvii., p. 97.

[3] *American Journal of Science*, vol. x., p. 229.

[4] *Nature*, 24, p. 406.

(3), beneath river-loam twenty to thirty feet thick. Supposing that the upper loam (4) represents the full Champlain flood-deposit, then 3 and 2 represent the later Champlain or early Terrace epoch.

In England, also, at Hoxne, similar flint implements, associated with bones of extinct animals, were found in strata *underlying the higher-level river-gravels, but overlying the bowlder-drift or true glacial deposit.* This fixes the age as Champlain. Many other examples of similar findings might be cited.

b. **Bone-Caves.—Engis Skull.**—In the caves of Belgium and Germany have been found human *bones* associated with extinct animals. The best example is that of the skull found in a cave at *Engis*, on the banks of the Meuse, near Liége. Of the great antiquity of this skull there seems to be no doubt. It was found in bone breccia, associated with bones of Quaternary, *extinct* species and *living* species, *beneath a stalagmitic crust.* This association unmistakably indicates the middle or latter part of the Quaternary period.

Neanderthal Skull.—In a cave at Neanderthal, near Düsseldorf, was found a very remarkable human skeleton, which has greatly excited the interest of scientific men. The limb-bones are large, and the protuberances for muscular attachments very prominent; the skull very thick, very low in the arch, and very prominent in the brows. It has been supposed by some to be an intermediate form between man and the ape; but, according to the best authority, it is in no respect intermediate, but truly human. It is probably the skeleton of a man exceptionally muscular in body and low in intelligence. The evidences of antiquity are

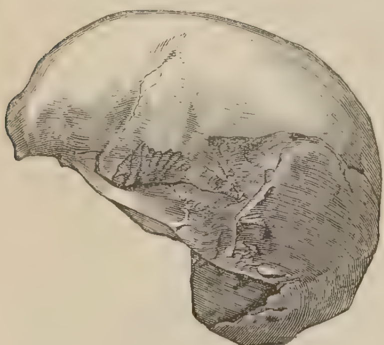


Fig. 898.—Engis Skull, reduced (after Lyell).

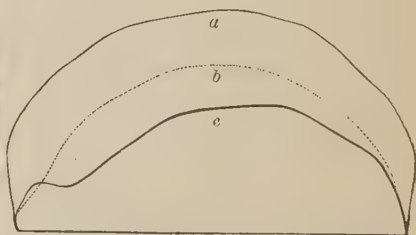


Fig. 899.—Comparison of Forms of Skulls: *a*, European; *b*, the Neanderthal Man; *c*, a Chimpanzee (after Lyell).

far less complete than in the case of the Engis skull, though it probably belongs to the same epoch. The Engis skull, on the other hand, is a *well-shaped average human skull.* A figure of the Engis skull is given above (Fig. 898), and a comparison in outline of the Neanderthal with the ape and European (Fig. 899).

Mentone Skeleton.—Only a few years ago an almost perfect skeleton of a Palæolithic man was found in a cave at Mentone, near Nice. It is that of a tall, well-formed man, with average or more than average-sized skull, and a facial angle of 85°. The antiquity of this man is undoubted, for his bones are associated with those of the cave-lion, cave-bear, rhinoceros, reindeer, together with living species. The bones of the skeleton are all in place, surrounded with the implements of the chase (flint implements), and the spoils of the chase, viz., the bones of reindeer, *perforated* teeth of stag, etc. Of the latter, twenty-two lay about his head. These are supposed to have been worn as a chaplet. This Quaternary man seems to have laid himself down quietly in his cave-home and died.

All these, and many more which might be mentioned, belong to the *early Palæolithic*, although the last is possibly a transition to the next or Reindeer age. They were contemporaneous with the mammoth, the rhinoceros, the hippopotamus, the cave-bear, the cave-lion, the cave-hyena, and other extinct animals ; but the reindeer had not yet, to any extent, invaded Middle Europe from the north. They seem to have been savages of the lowest type, living by hunting and dwelling in caves. There is no evidence of *agriculture* or of *domestic animals*. In many cases there have been found some anatomical characters of a low or animal type, such as *flattened shin-bones*, very *prominent occipital protuberance*, less than usual separation between the *temporal ridges*, large *size of the wisdom teeth*, etc. But all these characters are found now in some savage races, either as racial or as individual peculiarities. The earliest men yet found are in no sense connecting links between man and ape. They are distinctively and perfectly human, and even in many cases of far better conformation than the lowest types now living.

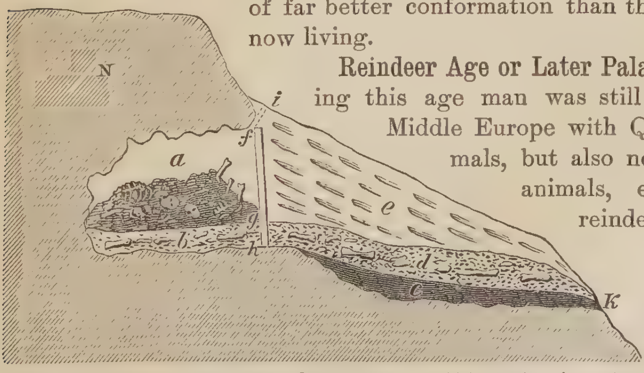


FIG. 900.—A Section of the Aurignac Cave: *a*, vault in which remains of seventeen human skeletons were found ; *b*, made ground, two feet thick, in which human bones and entire bones of extinct and living mammals, and works of art, were imbedded ; *c*, layer of ashes and charcoal, eight inches thick, with broken, burnt, and gnawed bones of extinct and living mammals, also hearth-stones and works of art ; *d*, deposit with similar contents ; *e*, talus washed down from hill above ; *f g*, slab of stone which closed the vault ; *f i*, rabbit-burrow, which led to discovery.

Reindeer Age or Later Palæolithic.—During this age man was still associated in Middle Europe with Quaternary animals, but also now with arctic animals, especially the reindeer. It probably corresponds with the Second Glacial epoch in Europe, and the full Terrace epoch in America.

Aurignac Cave.—This sepulchral cave and its rich contents were accidentally discovered by a French peasant. Fig. 900, page 595, is a diagram section of the cave, taken from Lyell.

On removing the talus, *e*, a slab of rock, *f g*, was exposed, covering the mouth of the cave, *a*. In this cave were found seventeen human skeletons of both sexes and of all sizes, together with entire bones of extinct animals and works of art. Outside of the cave was found a deposit, *c* and *d*, consisting of ashes and cinders, mingled with burnt and split and gnawed bones of recent and extinct animals, and works of art. The conclusion reached by M. Lartet is, that this was a family or tribal burial-place; that in the cave along with the bodies were placed funereal gifts in the form of trinkets and food; and that the funereal feast was cooked and eaten on the level space in front of the cave; and, finally, that carnivorous beasts gnawed the bones left on the spot. It is evident that the Aurignac men practised religious rites which indicated a belief in immortality.

The following is a list of the animals the remains of which were found in and about the cave; those marked † are either wholly extinct or extinct in this locality:

FAUNA OF AURIGNAC CAVE.

CARNIVORES.		HERBIVORES.	
†Cave-bear	5 or 6	†Mammoth	2 molars.
Brown bear	1	†Rhinoceros	1
Badger	1 or 2	†Horse	12–15
Polecat	1	†Ass	1
†Cave-lion	1	Hog	1
Wild-cat	1	Stag	1
†Cave-hyena	5–6	†Irish elk	1
Wolf	3	Roebuck	3–4
Fox	18–20	†Reindeer	10–12
		†Aurochs	12–15

Perigord Caves.—In Southern France, along the course of the river Vézère, are found many caves in which are preserved many interesting relics of man. The Palæolithic Aquitanians seem to have been somewhat more advanced, and of a more peaceful temper, than the early Palæolithic men already described. Although there is no evidence of agriculture, they lived by *fishing* as well as by hunting. This is shown by the number of fishing-hooks of bone found there. They seemed also to have had a taste and some skill in drawing, for they have left some drawings of contemporaneous but now extinct animals, especially the mammoth, the reindeer, and the horse. Fig. 901 is a piece of reindeer-horn on which is a rude etching of a mammoth.

FIG. 901.—Drawing of a Mammoth by Contemporaneous Man.

Conclusions.—It seems evident that in Europe the earliest men were contemporaneous with a large number of now extinct animals, and were a principal agent in their extinction; that they saw the flooded rivers of the Champlain epoch, and the great glaciers of the Second Glacial epoch; but there is no reliable evidence yet of their existence before or even during the *true Glacial* or ice-sheeted epoch.[1]

Neolithic Man; Refuse-Heaps; Shell-Mounds; Kitchen-Middens.

In Northern Europe, especially in Denmark, are found shell-mounds of great size, 1,000 feet long, 200 feet wide, and ten feet high. They are probably the accumulated refuse of annual tribal feasts. The early races of men in all countries seem to have had the custom of gathering in large numbers at stated intervals, and feasting on shell-fish and other animals, and leaving their remains in large heaps to mark the spot of assembly. The evidences of a very marked advance are found in these heaps. The implements are many of them carefully shaped or else polished by rubbing. There are no longer any remains of extinct animals, but only of living animals; and there are now found remains of at least one domestic animal, viz., the dog, though not yet any evidence of agriculture.

Transition to the Bronze Age—Lake Dwellings.—In the Swiss, Austrian, and Hungarian lakes are found abundant evidences of a more advanced race than any yet mentioned, which had the singular custom of dwelling in houses constructed on piles in the lakes, and connected with the land by means of piers or bridges. Similar lake-dwellings are found *now* in New Guinea and in South America, and very recently, by Lieutenant Cameron, in Africa.[2] By means of dredging, a great number and variety of implements of polished stone and of bronze have been obtained. Some of these were evidently used for ornament, some

[1] Some evidences of Glacial man, which seem somewhat more reliable, have recently been found in England, but it may be only the *Second Glacial* epoch.

[2] *Nature*, vol. xiii., p. 202, January, 1876.

for domestic purposes, some for agriculture ; some were weapons of war, some fishing-tackle. Many of these are wrought with great skill and taste. *Domestic animals*—ox, sheep, goat, and dog; *cereal grains*—wheat and barley; *fruits*—wild apples, blackberry, etc.; coarse cloth, not woven but plaited—have also been found. In a word, we have here all the evidences of communities far above the state of savagism.

From this time the history of man may be traced, by means of his remains, through the time of Megalithic structures, through the Roman age, step by step, to the present time. But this belongs to the archæologist, not the geologist. The Neolithic may be regarded as the beginning of the Psychozoic era—the connecting link between geology and archæology. The Bronze age and all that follows it belong clearly to archæology.

Primeval Man in America.

Supposed Pliocene Man.—Several cases are reported of human bones and works of art having been found in the sub-lava drift described on page 584. These cases are none of them thoroughly well attested, though the evidence is such as to make us suspend our judgment. The best-attested cases are the Calaveras skull mentioned by Whitney, and the Table Mountain skull reported by C. F. Winslow. Besides these there are several cases reported of mortars and pestles found in the sub-lava deposit. Many claim these as evidence of the existence of man in a somewhat advanced stage of progress (at least as much so as the Neolithic man of Europe), on the Pacific coast, during the Pliocene period. The doubts in regard to this extreme antiquity of man are of three kinds, viz.: 1. Doubts as to the Pliocene age of the gravels—they may be early Quaternary (p. 585). 2. Doubts as to the authenticity of the finds, no scientist having seen any of them *in situ*. 3. Doubts as to the undisturbed condition of the gravels, for auriferous gravels are especially liable to disturbance. The character of the implements said to have been found gives peculiar emphasis to this last doubt, *for they are not Palæolithic*, but *Neolithic*.

In any case, and whatever be the geological age of the sub-lava drift, if man should be undoubtedly found there, it would show an immense antiquity; for, since the lava-flow, cañons have been cut by the present rivers 2,000 or 3,000 feet deep in solid slate-rock.

Quaternary Man.—Even leaving out the supposed sub-lava-drift remains, the earliest appearance of man on the American Continent seems to have been on the Pacific coast, probably as migrants from Asia. There seems to be no doubt that the works of man have been found, associated with the remains of animals, both recent and extinct, in the superficial placer deposits (p. 585).[1] Among the extinct animals

[1] Whitney, "Geological Survey of California," vol. i., p. 252.

may be mentioned the elephant, the mastodon, and the horse. This corresponds with the period of primeval man in Europe.

Very recently on the eastern coast also, viz., in New Jersey and elsewhere, some very rude flint implements have been found by Abbot, which seem to prove the existence of man there in Glacial or interglacial times.[1] Shell-mounds are abundant on both the Atlantic and Pacific coasts, but these seem to be of later date than those of Europe.

Quaternary Man in Other Countries.—In *India*[2] Palæolithic implements, precisely like those found in Europe and elsewhere, were found, in 1873, associated with extinct species of elephant, hippopotamus, rhinoceros, and bear, in Quaternary deposits. In the South American bone-caverns human remains have been found associated with Quaternary animals.

Man, therefore, has been traced back with certainty to the later Champlain or early Terrace epoch. It is possible that he may be hereafter traced farther to the Glacial or pre-Glacial period. Some confidently expect that he will be traced to the Miocene, but this seems extremely improbable, for the following reasons:

a. He has been diligently searched for, without success. Now, while negative evidence is rightly regarded as of little value in geology, yet, in this instance, it is undoubtedly of far more than usual value, because man's *works* are far more numerous and far more imperishable than his *bones.*

b. Man probably came in with the present mammalian fauna. We repeat here the diagram illustrating the law of extinction and appear-

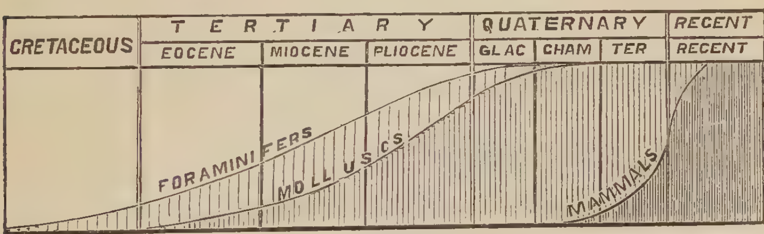


Fig. 902.

ance of species. It is seen that lower species are far less rapidly changed than higher. Living foraminifers may be traced back into the Cretaceous; living shells and other invertebrates to the beginning of the Tertiary: but living mammals pass out rapidly and disappear in the Middle Quaternary. Not a single species of mammal now living is found in the Tertiary. Shall man, the highest of all, be the only exception? Man is one of the present mammalian fauna, and came in with it.

But, again, several distinct mammalian faunæ have appeared and

[1] *American Journal of Science*, 1877, vol. xiv., p 246. [2] *Ibid.*, 1875, vol. x., p. 232.

disappeared since the beginning of the Miocene. The Miocene mammalian fauna is totally different from the Eocene; the Pliocene totally different from the Miocene; the Quaternary from the Pliocene; and the present from the Quaternary. This is graphically represented in

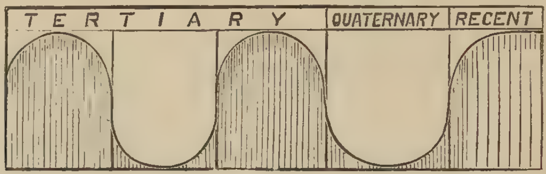


FIG. 903.—Diagram illustrating the Appearance and Extinction of Successive Mammalian Faunæ.

the diagram, Fig. 903, in which the alternate shaded and white spaces represent five consecutive mammalian faunæ (there are really more than five) overlapping each other, but substantially distinct. It seems in the highest degree improbable that man, a mammal, should survive the appearance and disappearance of several mammalian faunæ. If, therefore, man should ever be traced to the Miocene, it would probably be a different species of man—the genus *Homo*, but not the species *Sapiens*.

Time since Man appeared.—Geology reckons her time in periods, epochs, etc.; History hers in years. It is impossible to express the one chronology in terms of the other except in a very rough approximative way, for want of a reliable common measure. If Mr. Croll's theory of glacial cold should indeed prove true, then we might hope to measure man's time on the earth with some degree of accuracy. But in the absence of confidence in this theory, our only resource is to use the measure which we have already used on several occasions, viz., the effects of causes now in operation. This measure, however, can give but very rough approximate results.

There is no doubt that very great changes, both in physical geography and in the mammalian fauna, have taken place since man appeared. Judging by the rate of changes still in progress, we are naturally led to a conviction of a lapse of time very great in comparison with that recorded in history. On the other hand, some attempts to estimate more accurately by means of the growth of deltas in which have been found implements of the Roman age, the Bronze age, and the Stone age; and by the progressive erosion of lake-shores, which is supposed to have commenced after the Champlain epoch, have led to very moderate results, viz., 7,000 to 10,000 years. While these results cannot be received with any confidence, yet it is hoped that many such will continue to be made.

In conclusion, we may say that we have as yet no certain knowledge

of man's time on the earth, unless we adopt Croll's theory of the Glacial climate. It may be 100,000 years, or it may be only 10,000 years, but more probably the former than the latter.

II.—Character of Primeval Man.

In regard to the second question, viz., the character of primeval man, we will make but one remark. We have seen that the earliest men yet discovered in Europe or America, though low in the scale of civilization, were distinctively and perfectly human, as much so as any race now living, and were not in any sense an intermediate link between man and the ape. Nevertheless, we must not forget that the cradle of mankind was probably in Asia. Man came to Europe and America by migration. The intermediate link, if there be any such, must be looked for in Asia. This question can only be settled by a complete knowledge of the Quaternary of that country.

In any case, man is the ruler only of the modern era. The presence of man in Quaternary times must be regarded as an example under the *law of anticipation* (p. 278). He only fairly *established* his supremacy in the Recent epoch, and therefore the age of man and the Psychozoic era ought to date from that time.

APPENDIX.

Page 48.

An admirable illustration of extreme inequality of the surface of ice is seen in the case of the small residual glacier still remaining on Mount Lyell, Sierra Nevada.[1] On the top of Mount Lyell there is an immense amphitheatre (*cirque*), filled with snow and ice. In August the surface of this ice-field is set with ice-blades, three to four feet high and only two feet apart, as in the section Fig. 38a. They are probably formed as follows: In winter, when the snow is deep and light, it is blown into wind-ripples on a large scale. These soon become fixed by surface melting and freezing, and then the greater action of the sun in the troughs, partly by the reverberation of heat and partly by accumulation of dust there, causes these to become deeper and deeper. It is necessary to remember that there is neither snow nor rain in this region after about the first of May until November.

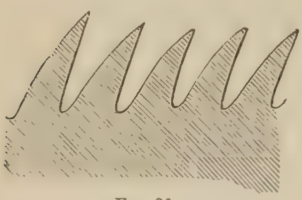


Fig. 38a.

Page 60.

Recent Theories.

Croll's Theory.—Croll has recently, in his work on "Climate and Time," brought forward a theory which has attracted much attention. Moseley had previously attempted to prove the untenableness of all theories attributing the motion of glaciers to gravity, by showing experimentally that the *shearing force of ice* (the force necessary to slide one layer on another, as in differential motion) is many times greater than that portion of gravity which acts in the direction of the

[1] *See* paper by the writer, *American Journal of Science*, vol. v., p. 333, 1873.

slope of a glacial bed. Croll, accepting Moseley's view in regard to the shearing force of ice, but accepting also gravity as the moving force of glaciers, thinks to reconcile these by supposing that there is in ice, when subjected to heat, a *momentary* loss of cohesion by melting, which is *transferred from molecule to molecule*, giving rise thereby to a kind of intestine molecular motion similar in its effects to viscosity. The process is as follows: Heat falling on glacier-ice melts its surface. The water thus formed runs down to a lower level, and is again refrozen. Now, what takes place *conspicuously* on the surface takes place *molecularly* in the interior of the ice. In every part the ice-molecules are melting and refreezing. A molecule takes up heat by melting, runs down to an infinitesimally lower point, refreezes, and in so doing gives up its heat and melts another molecule, which in its turn seeks a lower position, and, by refreezing, transfers its heat and fusion to still another molecule, and so on. Thus the whole glacier is in a state of molecular movement downward.

The theory is ingenious, but somewhat obscure. We will therefore dismiss it with two remarks: 1. Moseley's objection to gravity as the moving force of glaciers is invalidated by the fact that he does not take sufficiently into account the effect of *time* and *slowly applied pressure* in determining shearing; and *in stiffly viscous substances time is the controlling element.* 2. Until we understand better than we now do the actual behavior of ice-molecules in glacial motion, Croll's theory must be regarded only as a modification (though, perhaps, an important modification) of Forbes's; for it supposes a *molecular differential* motion determined by gravity, and into which both heat and time enter as elements. It is an attempted *physical explanation of the viscosity of ice.*

Thomson's Theory.—Some time ago James Thomson brought forward a theory which deserves far more attention than it has yet received. Thomson shows that the fusing-point of ice is *lowered*, and, therefore, that ice at or near its fusing-point (as is the fact in glaciers) is *promptly melted by pressure.* Now, it is obvious that, in the differential motion of glaciers, whatever point at any moment receives the greatest stress of pressure must melt and give way, and, the stress being relieved, it must immediately again refreeze. Meantime, by change of relative position of parts, the stress is transferred to some other point, which in its turn melts, gives way, is refrozen, and transfers its stress to still another point, and so on. If we compare this theory with Tyndall's, in both cases the ice gives way at the point of greatest stress—in the one case *by fracture*, in the other *by melting.* Differential motion, therefore, in the one case is by *fracture, change of position, and regelation*; in the other by *melting, change of position, and regelation.*

Page 168.

To this, according to Faye,[1] must be added still another cause. As soon as the water collects in the depressions formed by unequal radial contraction, its very presence would tend to increase the cooling and contracting of these parts, and thus to deepen still farther the depressions. This effect results (1) from the greater conductivity of water as compared with rock, and (2) from the circulation of ice-cold water from the poles along the sea-bottom (page 37).

Page 249.

There is another possible reaction by which it may have occurred. Gold sulphide, like other metallic sulphides, is soluble in alkaline sulphide solutions. The waters percolating through the deep gravels certainly contained alkaline sulphides. It is not improbable that hot alkaline sulphide waters dissolved both iron sulphide and gold, and redeposited them either by cooling or by neutralization of the alkali by humus acids.

Page 284.

To the same, or else to the Primordial, age, belong also the immense beds of iron ore, probably the greatest in the world, recently found in southern Utah. Pure iron ore occurs here in vertical, highly metamorphic strata, and by erosion has been left standing above the surface of the country as mountain ridges, or like huge black walls 1,000 feet long, 500 feet thick, and rising in castellated crags 200 to 300 feet high.[2]

Page 290.

To this, however, must be added such Archæan areas as may have been covered only by deposits *later* than Palæozoic. The largest of these is in the Basin region. The western half of this region (Nevada basin) is largely covered with Jura-Trias, resting directly on the Archæan (King). The absence of the whole Palæozoic series shows that during Palæozoic times this area was land. Also the Appalachian Archæan area and Silurian land was probably larger than represented, having lost by subsequent subsidence, and been covered by subsequent deposits on its eastern border.

Page 399, 1.

Although the Limuloids in distinct forms appear first in the Carboniferous, yet it is probable that transition-forms may be traced even

[1] *Comptes Rendus*, vol. xc., p. 1185, 1880.

[2] Newberry, "Genesis of Iron Ores," *School of Mines Quarterly*, 1880.

to the Upper Silurian. Such transition-forms are of extreme interest as throwing light on evolution. If with Packard we divide all Crustaceans into two sub-classes, *Palæo-caridæ* and *Neo-caridæ* (old style and new style Crustaceans), then Trilobites, Eurypterids, and Limuloids belong to the Palæocaridæ. That all these were derived from Trilobites is rendered probable by the transition-forms shown in Figs. 543a and 543b. As already seen (p. 325), the same view is sustained by embryology.

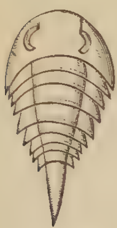


FIG. 543a.

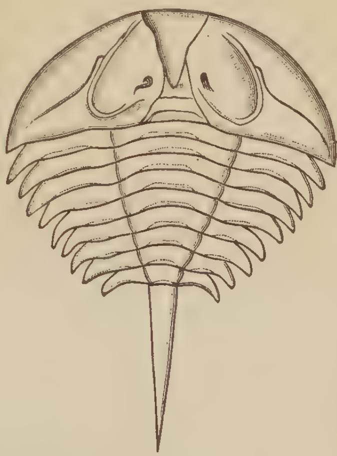


FIG. 543b.

FIGS. 543a, 543b.—543a. Palæoniscus aculeatus (after Nieskowski): a Eurypterid from Upper Silurian. 543b. Neolimulus falcatus (after Woodward): a Limuloid from Upper Silurian.

Page 399, 2.

It should be observed, however, that the three highest orders, viz., Dipters (flies), Hymenopters (bees, ants, etc.), and Lepidopters (butterflies), are still wanting.

Page 399, 3.

About one hundred Palæozoic species are known, of which forty are American. All Palæozoic insects are remarkable for their generalized structure (Scudder).

Page 412.

At the same time great changes took place in the West also. The Utah basin region was upheaved to form land, the Nevada basin region sank and became sea-bottom, and the Pacific shore-line was transferred eastward to the 117th meridian about Battle Mountain. In other

words, the Basin region Palæozoic continent was transferred eastward its own breadth to form the Basin region Mesozoic continent (King).

Page 416.

Some Recent Discoveries.—In the Permian of Illinois, Western Texas, and New Mexico, have been recently discovered and described by Cope and Marsh at least fifty species of vertebrates. Of these, sixteen species were fishes (Sauroids and Placoids), seven amphibians, and twenty-eight true reptiles. The amphibians of the Coal and Permian (Labyrinthodonts and Ganocephala) have been united under the name *Stegocephali* (covered head) on account of the bony plates with which their heads are protected (Fig. 586a), and the reptiles of the Permian are called by Cope *Theromorpha* (beast-form), on account of the possession of characters connecting them with the lowest mammals, the *Monotremes*. The stegocephalous amphibians of the Coal and Permian and the theromorphous reptiles of the Permian and Triassic were remarkable generalized types, the one connecting together fishes, amphibians, and reptiles, the other amphibians, reptiles, and mammals. It is believed by many (Cope and Owen) that in these theromorphous reptiles we have the probable ancestors of the marsupial mammals which appeared in the Upper Triassic.

Fig. 586a.

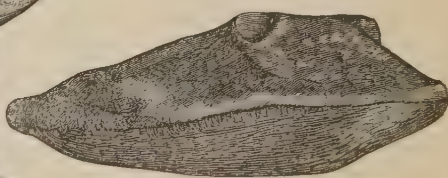


Fig. 586b.

Fig. 586a.—Eryops megacephalus. 586b. Side view, × $\frac{1}{10}$ (after Cope).

Page 447.

This unique specimen has been but lately described, and the original is deposited in the Museum of Yale College. One remarkable feature is the great length of the tail, which is vertically expanded at

the end; it may have been employed as a rudder in flight. Professor Marsh has recently described a Pterodactyl (*Dermodactylus montanus*) from the Jurassic beds of Wyoming, the only one yet known from this formation in America.

Many species of Pterodactyl have been found, ranging in size from two feet to twenty feet in alar extent. They lived throughout the whole Jurassic and into the Cretaceous period.

Page 449.

The Berlin Specimen.—A second specimen of Archæopteryx, discovered in 1873 and now in the museum at Berlin, shows several char-

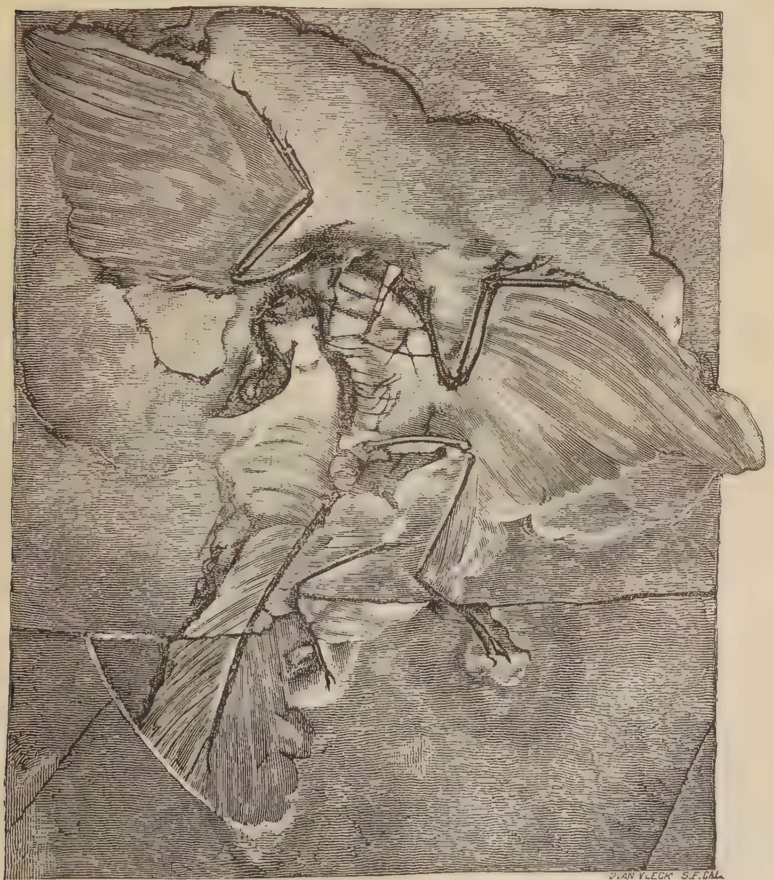


FIG. 688a.—Archæopteryx macroura, Berlin specimen (after Seeley).

acters not observable in the other. A careful examination of both specimens has enabled Marsh to make out many additional characters, the most important of which are—distinct but minute teeth; separate metatarsals, as well as metacarpals, as in reptiles and the embryo of birds; bi-concave vertebræ; pelvic bones separate as in Dinosaurs; shoulder girdle wholly bird-like, with distinct furcula (some Dinosaurs also have clavicles), and a broad sternum, probably keeled. Vogt thinks that there were no other feathers except quills of the wings and tail, and along the outsides of the tibiæ; but this conclusion seems unwarranted, for decomposition might well destroy the feathers except in these outlying positions. On the whole, the result of the examination of this later specimen is to bring into still stronger relief its completely intermediate character. While most agree that bird characters predominate, and that it should be called a *reptilian bird*, others, like Vogt, think that the reptilian characters predominate, and that it should be regarded as a *feathered flying reptile*.[1] In Fig. 688a we give a copy of a photograph of the Berlin specimen.

Page 453.

As the strata of the New Jersey patch dip in contrary direction —i. e., to the west—and also show marks of shore-line, Russell[2] thinks

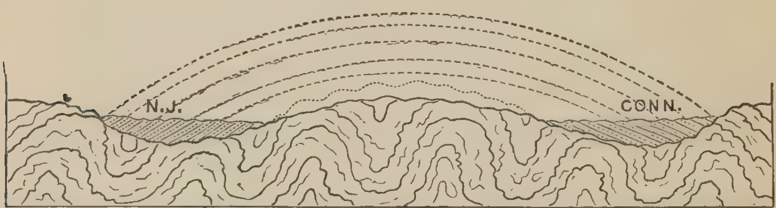


FIG. 695a.—Section across the New Jersey and Connecticut sandstones showing supposed eroded anticline.

that these, and in fact all the patches, are remnants of one originally extensive deposit, stretching from Nova Scotia to Carolina, which has been lifted along the middle into an anticline, and subsequently carried away by erosion, leaving only portions of the two edges, as shown in the diagram, Fig. 695a.

[1] "Archives des Sciences," vol. ii., p. 702, 1879; *Geological Magazine*, viii., 300, 1881; *American Journal of Science*, xxii., 337, 1881.

[2] "Annals of New York Academy of Science," vol. i., p. 220, 1878.

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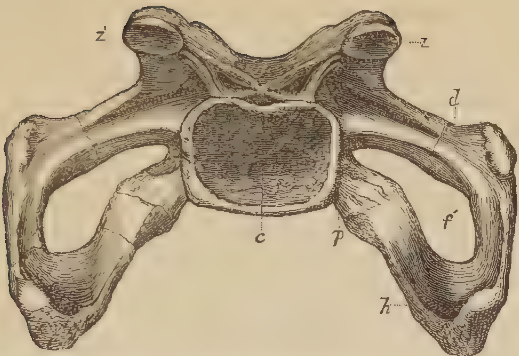

Fig. 727a (2).—Cervical vertebra of Apatosaurus laticollis (after Marsh), back view. z' posterior zygapophysis.

Page 510.

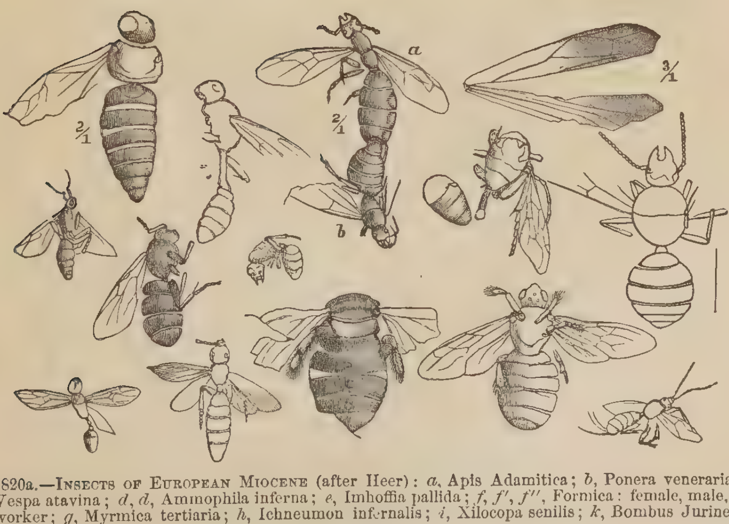

Fig. 820a.—Insects of European Miocene (after Heer): *a*, Apis Adamitica; *b*, Ponera veneraria; *c*, Vespa atavina; *d*, *d*, Ammophila inferna; *e*, Imhoffia pallida; *f*, *f′*, *f″*, Formica: female, male, and worker; *g*, Myrmica tertiaria; *h*, Ichneumon infernalis; *i*, Xilocopa senilis; *k*, Bombus Jurinei; *l*, Scalea saussureana.

Page 512.

But probably the richest beds in insects yet found are at Florissant, Colorado. Here fresh-water shales of *Green River* age are black with remains of insects of all orders now existing. According to Scudder,[1] about 1,000 species are recognizable, besides many plants, several fishes, and a bird with feathers preserved. Here also, as in Europe, Hymenopters and Coleopters are most abundant, and all the species indicate tropical climate. At Florissant, in Eocene times, there was a lake, and insects were cast ashore and accumulated in the manner already described.

Page 521.

The most characteristic representative of the Horse family in the Old World Miocene was a three-toed animal called *Hipparion*. A restoration of this graceful creature is given in Fig. 839a.

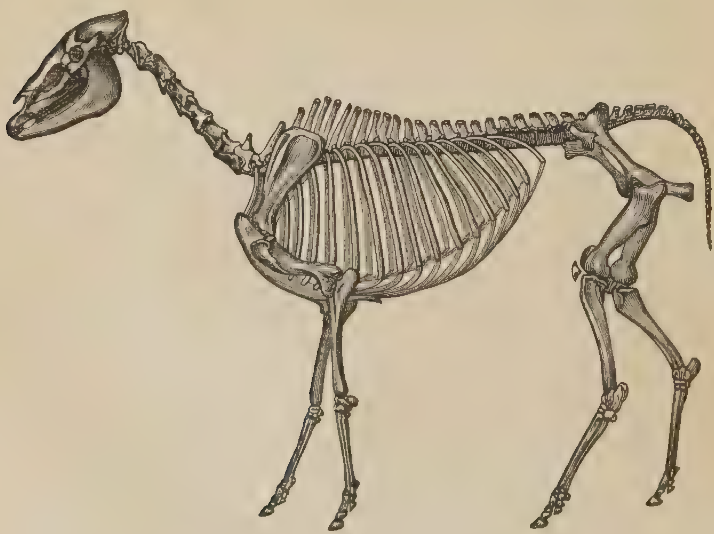

FIG. 839a.—Skeleton of Hipparion gracile restored (after Gaudry).

[1] "Bulletin of the Geological Survey," vol. vi., No. 2.

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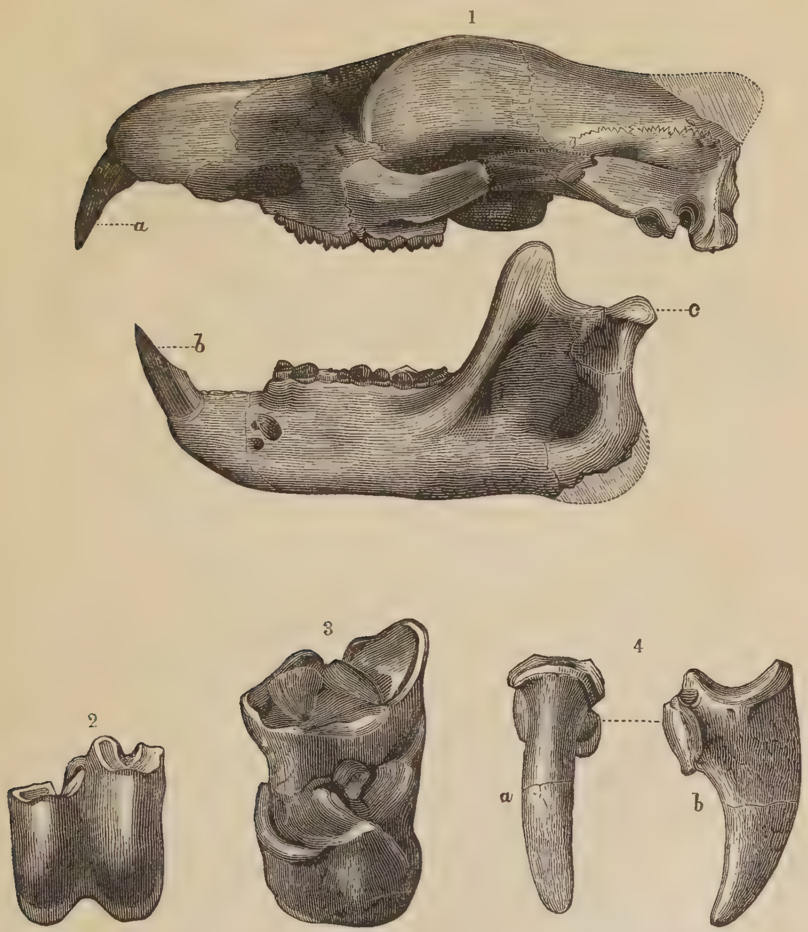

FIG. 847a.—EOCENE MAMMALS: Tillodontia of Marsh. 1, skull; 2, 3, upper and lower molars; 4, ungual phalanx.

Page 528.

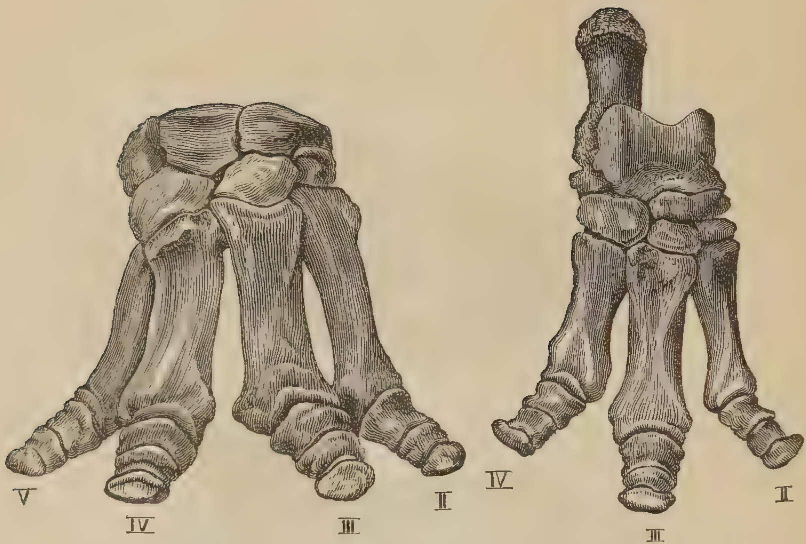

FIG. 848a.—MIOCENE MAMMAL: Brontotherium of Marsh. Fore and hind feet, × $\frac{1}{12}$.

Page 561.

Glacial lakes are formed in several ways: (*a*) They may be rock basins scooped out by glaciers either where the rock is softer or where the angle of slope of the glacial bed becomes suddenly less; or (*b*) they may be formed by damming of drainage waters behind terminal moraines of retiring glaciers; or (*c*) by the disappearance of snows from old *cirques*, the fountains of ancient glaciers; or (*d*) along northern coasts by the elevation of ancient fiords which, as seen in Fig. 872, are always deeper in their upper reaches. Examples of *a*, *b*, and *c*, are common in the Sierra and other high mountain regions, *a* and *c* near the summits, and *b* a little lower down. The marshes and meadows so common in old glacial regions are often formed by the filling up of glacial lakes. Many of the lakes of Norway, and even of Scotland, are examples of *d*—they are elevated fiords. The great Canadian lakes have been by some attributed to the scooping of the ice-sheet, but they are more probably drainage valleys dammed up by Drift.[1]

[1] Spencer, "American Philosophical Society," vol. xix., p. 300, 1881.

Page 592.

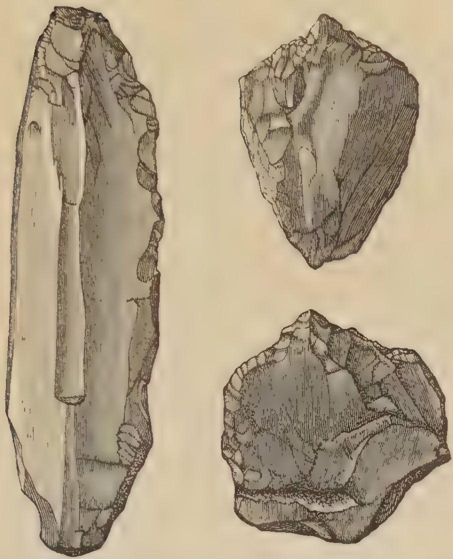

FIG. 896a.—Flint flakes collected by Abbé Bourgeois from Miocene Strata at Thenay (after Gaudry). Natural size.

A LIST OF THE PRINCIPAL AUTHORITIES FOR THE ILLUSTRATIONS IN THIS WORK, AND THE BOOKS FROM WHICH THEY HAVE BEEN TAKEN.

AGASSIZ, L. "Études sur les Glaciers"—"Poissons Fossiles."

AUTHOR. *Am. Jour. of Sci.*, III., vols. x. and xi.; also many (about 150) diagrammatic illustrations throughout this work.

BAILEY, J. W. *Am. Jour. of Sci.*, II., i.

BRADLEY, F. H. Geological Chart of the U. S.

BRONGNIART, A. "Histoire des Végétaux Fossiles."

BUCKLAND, W. "Bridgewater Treatise."

CHAMBERLIN, T. C. "Kettle Moraine." "Trans. Wis. Acad. Sci.," 1879.

CONRAD, T. A. *Jour. Acad. Sci.*, Philadelphia.

COPE, E. D. Hayden's "U. S. Geog. and Geol. Surv.," vol. ii.—"Cretaceous Vertebrates;" Newberry's "Ohio Surv. Pal."—"Reptiles of the Coal;" "Proc. Am. Phil. Soc.," vols. xvii. and xix.—"Permian and Jurassic Reptiles."

DADDOW, S. H. "Coal, Iron, and Oil."

DANA, J. D. Wilkes's "U. S. Explor. Exped."—vol. on "Geology;" "Manual of Geol."

DAWSON, J. W. "Acadian Geology."

DE LA BECHE, H. "Geological Observer"—"Sections and Views of Geological Phenomena."

D'ORBIGNY, A. "Paléontologie et Géologie."

EMMONS, E. "Rep. Geol. of N. Y.;" "Rep. Geol. of N. C."

FAVRE, Prof. ALPH. "Archives des Sciences," vol. lxii.

FORBES, J. "Alps of Savoy."

FOSTER and WHITNEY. "Rep. on Geol. of L. Supr. District."

GABB, W. M. Whitney's "Geol. Surv. of California."

GAUDRY, A. "Monde Animale."

GEIKIE, A. "Great Ice Age."

GILBERT, G. K. "Geology of the Henry Mountains."

GÜNTHER, A. "Trans. Roy. Soc.," 1871.

GUYOT, A. "Physical Geography."

HALL, J. "Rep. Palæontology of N. Y.;" "Rep. Geol. of Iowa;" "Rep. on State Cabinet of N. Y."

HAYDEN, F. V. "Rep. Geog. and Geol. Surv. of Terr., 1871–'73," and several figures not yet published.

HEER, Prof. "Primeval World of Switzerland."

HILGARD, E. W. "Rep. Agric. and Geol. of Miss.," 1860.

HITCHCOCK, C. H. "Geol. Map of U. S."

HITCHCOCK, E. "Ichnology of Mass.," 1858.

HOLMES, W. H. Drawing of Geyser Eruption.

HOWELL, E. E. "U. S. Geog. Surv. by Wheeler," vol. iii.—"Geology."

JUKES and GEIKIE. "Manual of Geology."

HUXLEY, T. H. "Manual of Anat. of Vertebrates."

JACKSON, W. H. Photograph of Geyser Eruption.

Johnstone, A. K. "Phys. Atlas," last edition.

King, Clarence. "Geol. Surv. of 40th Parallel," vol. i.

Leidy, J. "Cretaceous Reptiles of U. S.;" "Smithsonian Contributions," 1865; "Fossil Vertebrates of U. S.;" Hayden's "Geol. Surv. of Terr.," vol. i.

Lesley, J. P. "Manual of Coal and its Topography."

Lesquereux, L. Owen's "Rep. Geol. of Ky.;" Owen's "Rep. Geol. Ark.;" Hayden's "Geog. and Geol. Surv.," vol. vi.; "Cret. Flora of U. S."

Logan, W. "Rep. Geol. Canada."

Lyell, C. "Principles of Geology;" "Elements of Geology;" "Antiquity of Man."

Mantell, G. A. "Fossils of British Museum."

Mâout and Decaisne. "General System of Botany."

Marsh, O. C. "Jurassic and Cretaceous Reptiles and Birds, and Jurassic and Tertiary Mammals;" *Am. Jour. of Sci.*, 1871–'82.

Meek and Worthen. "Geol. Surv. of Ill.," vols. ii., iii., iv., v., vi.

Meek, F. B. Whitney's "Geol. Surv. California," vol. i.; Newberry's "Geol. Surv. of Ohio Pal.," vols. i. and ii.; "Palæontology of Upper Missouri;" "Smithsonian Contributions," 1864.

Murchison, R. I. "Siluria."

Newberry, J. S. "Rep. Geol. Surv. of Ohio;" "Geol. of Macomb Expedition;" "Pacific R. R. Reports," vol. vi.

Nicholson, H. A. "Manual of Palæontology;" "Manual of Zoölogy;" "Ancient Life History."

Owen, D. D. "Rep. Geol. of Wisconsin, Iowa," etc.

Owen, R. "British Fossil Mammals;" "Palæontology."

Packard, A. S. "Life-Histories;" "Manual of Zoölogy."

Phillips, J. "Manual of Geology;" "Geology of Oxford."

Pictet, F. J. "Traité de Paléontologie."

Powell, J. W. "Exploration of Colorado River;" "Geology of Uintah Mountains."

Rogers, H. D. "Rep. Geol. of Pennsylvania."

Safford, J. M. "Rep. Geol. of Tennessee."

Seeley, H. G. *Geol. Mag.*, vol. viii., 1881.

Scudder, S. H. Worthen's "Rep. Geol. of Ill.," vol. iii.

Sharpe, D. *Quar. Jour. Geol. Soc.*, vol. iii., 1847.

Sorby, H. C. *Philosophical Magazine*, 2d series, vol. xi.

Stevenson, J. J. Wheeler's "U. S. Geog. Survey," vol. iii.—"Geology."

Taylor, R. C. "Statistics of Coal."

Tyndall, J. "Glaciers of the Alps."

Upham, Warren. "Ice Sheet Moraine;" "Geol. Surv. of Minn.," 1880.

Wailes, B. L. C. "Rep. Agric. and Geol. of Miss.," 1854.

Walcott, C. D. "Rep. N. Y. Cab. of Nat. Hist.," 1877.

Wallace, A. R. "Geographical Distribution of Animals;" "Island Life."

Ward, H. Illustrated Catalogue of Casts.

Wheeler, G. M. "U. S. Geog. Surv. west of 100th Meridian."

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